VOLUME 56 NUMBER 3

THE JOURNAL OF GEOLOGY

May 1948

CAVE-IN LAKES IN THE NABESNA, CHISANA, AND TANANA RIVER VALLEYS, EASTERN ALASKA[1]

ROBERT E. WALLACE
State College of Washington, Pullman, Washington

ABSTRACT

Cave-in lakes resulting from ground caving following the thawing of permafrost have developed in areas underlain by fine-grained sediments in the Nabesna, Chisana, and Tanana River valleys of eastern Alaska. It is suggested that the vegetal cover has an important control over the presence of permafrost and that a cave-in lake is initiated by a break in this cover. Once a lake is formed, the banks retreat at a rate indicated to be of the order of a few inches a year. The recession of lake banks thus enlarges the lake and is responsible for a typical sequence of areal patterns of the cave-in lakes.

INTRODUCTION

The present study of cave-in lakes in the Nabesna, Chisana, and Tanana River valleys of eastern Alaska was done as part of an investigation of permafrost by the Geological Survey which, in part, was conducted under the sponsorship of the Military Intelligence Division, Office of the Chief of Engineers, U.S. Army. The purpose of the study was to develop criteria to be used in determining permafrost conditions by means of aerial reconnaissance.

Observations were made during October and November, 1945, within a radius of approximately 15 miles of Northway, Alaska, near latitude 63° N. and longitude 142° W., approximately 30 miles west of the Alaskan-Canadian boundary.

DEFINITIONS

Permafrost, a condition in which the ground temperature remains below freezing throughout a considerable number of years. The condition is defined as "dry permafrost" if no ice is present. "Perennially frozen ground," "permanently frozen ground," and "pergelisol" (Bryan, 1946, p. 640) are other terms that are used for permafrost.

Cave-in lakes, lakes whose basins result from collapse following volume contraction due to thawing of permafrost. The term "thermokarst" has also been applied to these lakes and alludes to the similarity of origin and appearance of these lakes to karst lakes in areas underlain by limestone. "Kettle lake" and "Kettle-hole lake" have also been used in referring to these lakes.

GEOLOGIC SETTING

The area studied (figs. 1 and 2) is within a radius of 15 miles of the point at which the Chisana and Nabesna rivers

[1] Published by permission of the Director, United States Geological Survey and Office of the Chief of Engineers, United States Army. Manuscript received November 6, 1947.

join to form the Tanana River. Most of the area is southwest of the Tanana and Chisana rivers. An area immediately underlain by crystalline rocks is northeast of these two rivers.

The broad floodplains of the Nabesna, Chisana, and Tanana rivers lie in the dissected floor of an old lake basin. Remnants of the old lake sediments, including

ly 20 miles from its mouth. A terminal moraine on the south side of the ridge marks the greatest advance of the Nabesna Glacier. The river has incised the moraine to a depth of about 100 feet. Outwash material from the glacier has been carried northward through the notch and has been spread out in the form of an alluvial fan on the dissected floor of

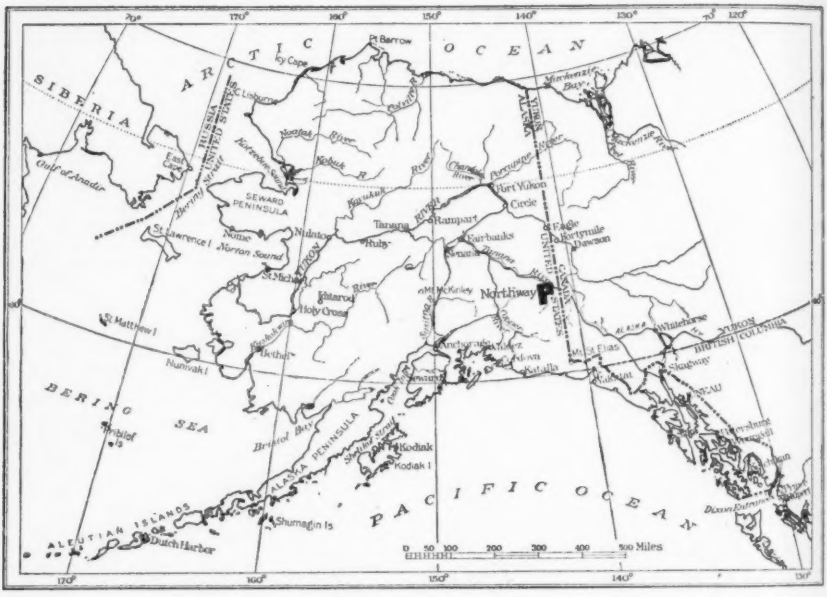

FIG. 1.—Index map of Alaska, showing Northway area

some stream-borne gravels, form terraces, which in some places are surrounded by the floodplains; elsewhere the terraces border the floodplains. The terraces are about 100–200 feet above the present river levels. They have been subjected to wind action, so that large areas are covered by sand dunes, many of which have a relief of 100 feet. The dunes are covered by vegetation and are almost inactive at present.

The Nabesna River flows through a notch in a ridge of bedrock approximate-

the lake basin. The present Nabesna River is slightly incised in the upper part of the fan.

DISTRIBUTION OF CAVE-IN LAKES

Cave-in lakes have been reported from many parts of Alaska; however, few detailed descriptions are available. Cave-in lakes are manifestations of permafrost; their distribution, therefore, is coextensive with that of permafrost. The southern limit of permafrost is at approximately 60° N. in southwestern Alaska, paral-

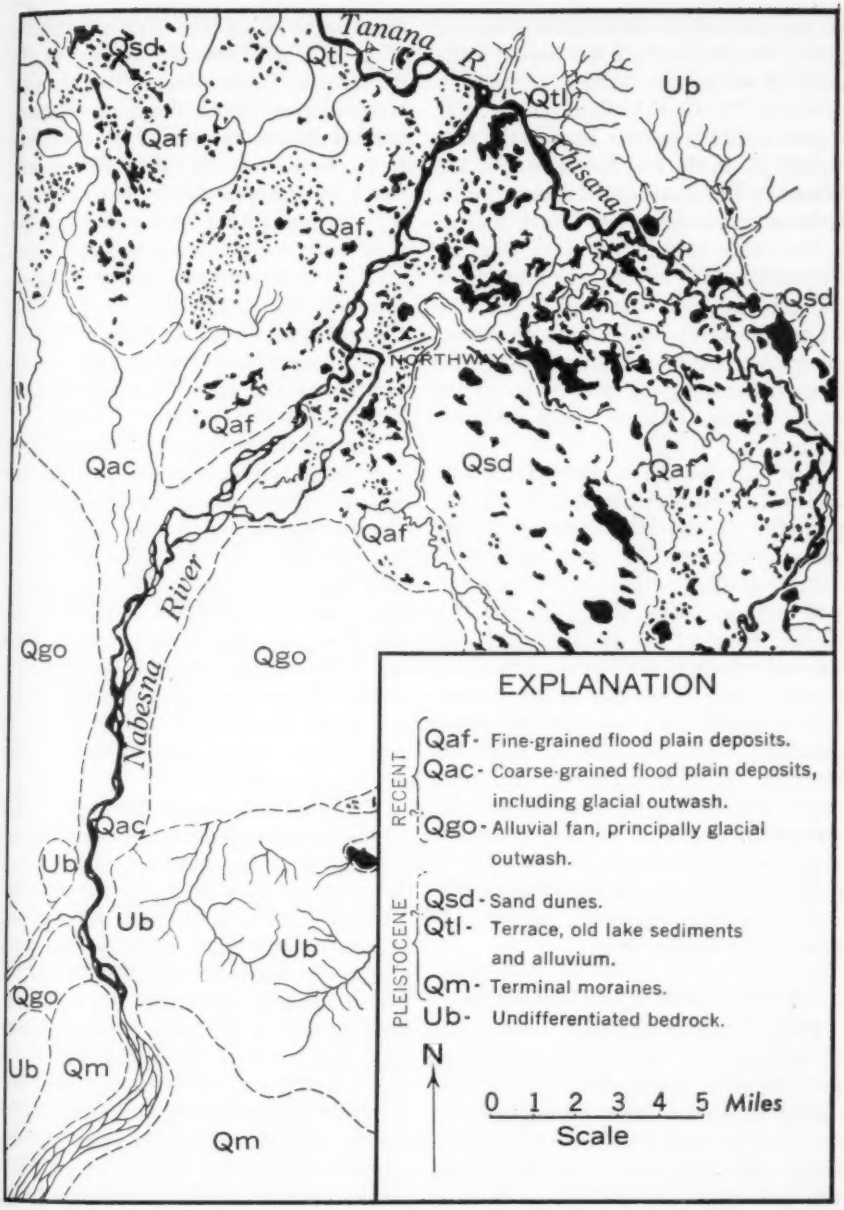

FIG. 2.—Geologic map of part of Nabesna, Chisana, and Tanana river area, Alaska, showing terrain divisions.

lels the coast a few miles inland along the Gulf of Alaska, and is a few tens of miles north of Anchorage, Alaska, at approximately 62° N. (Smith, 1939, pl. 14).

Almost all the cave-in lakes in the area studied are in the low flood plains of the Nabesna, Chisana, and Tanana rivers. Although permafrost was found in most of the other terrain divisions (fig. 2), little evidence of caving was found. For example, although many lakes are present in the sand-dune areas, no caving along the borders of these lakes was noticed. Some caving was found in the terrace areas, but no lakes had developed.

This distribution apparently is controlled to considerable extent by the grain-size of the sediments which are characteristic of the terrain units. Silts and fine-grained sediments change greatly in volume (Taber, 1929, pp. 460–461; Muller, 1945, p. 64) upon freezing and thawing, whereas well-sorted sands and gravels change but little or not at all.

The distribution of cave-in lakes, therefore, seems to coincide with the areas in which fine-grained sediments occur within the regions affected by permafrost. Cave-in lakes thereby become an excellent key, recognizable in aerial photographs, for determining permafrost-bearing ground subject to slumping upon thawing.

CROSS SECTION OF CAVE-IN LAKES

Probing and drilling with hand augers by members of the Geological Survey and extensive drilling and temperature testing in certain areas by engineers of the St. Paul district indicate to a certain extent the distribution of permafrost near and under several cave-in lakes in the floodplain of the Nabesna River.

The cave-in lakes investigated are very shallow and have relatively flat bottoms, most being less than a maximum of 5–10 feet below the surface of the floodplains. The borders of the lakes are typically precipitous, dropping off steeply from the general level of the floodplain to the bottom of the lakes. The vegetal cover left unsupported by caving droops over the precipitous bank and, where the drop is not too great, forms a continuous mat over the cave-in bank and the adjacent bottom of the lake (fig. 3). Where the mat is not flexible or if the drop is too great, large cracks form parallel to the borders of the lake. In extreme cases large land slumps occur.

The depth to the permafrost table under the floodplain ranges from a few inches in places where vegetation affords the best insulation to approximately 10 feet where it provides poor insulation. The depth beneath the average spruce forest cover, typical of the low floodplains, is 1 or 2 feet. The ground in these spruce forests commonly is covered by a mat of sphagnum moss, 2–8 inches thick, low-bush cranberries, *Ledum*, and, in more open areas, dwarf birch, blueberries, and grasses.

The depth to permafrost at the edges of the cave-in lakes increases precipitously (fig. 3). No permafrost was encountered down to a depth of 12 feet, the greatest depth that could be reached with the auger used, in holes that were put down just offshore. No permafrost was found at a depth of 12 feet below the lake surface or 8–10 feet below the lake bottoms in other holes that were put down in the centers of lakes. The character of the permafrost at greater depths below the lakes is not known. The engineers at the St. Paul district have drilled several holes approximately 50 feet deep in the floodplains. These penetrated the entire thickness of the permafrost.

AREAL PLAN OF LAKES AND SEQUENCE OF DEVELOPMENT

A sequence of cave-in lake development was recognized in the Northway area. This sequence can be divided into four stages, which may be referred to as youthful, early mature, late mature, and old age.

The early mature stage (fig. 5) is designated as that in which several simple lakes have joined to form an aggregate. The typical borders of lakes at this stage are "scalloped" because of the original circular shape of the individual lakes.

The late mature stage of the sequence is defined as that in which aggregates of

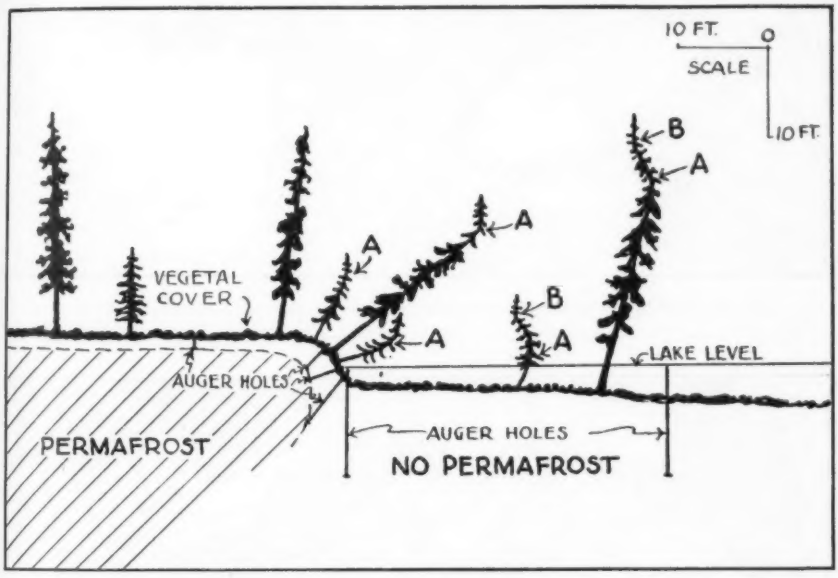

FIG. 3.—Diagram of cross section of bank of cave-in lake, showing tilted and S-shaped trees and distribution of permafrost. *A*, First bend, formed when receding bank reached the base of the tree. *B*, Second bend, formed after receding bank passed beyond the tree.

The youthful stage (fig. 4) of the sequence begins when caving of the ground, as the result of thawing, forms a small basin in which water accumulates. As the permafrost in the banks of the depression thaws progressively outward, the banks retreat from the initial point, forming a roughly circular lake which is continually enlarging in area. Some simple circular lakes, characteristic of the youthful stage, are as much as 600 feet in diameter.

lakes have coalesced with other aggregates and the whole system has been integrated, commonly by intersection of a drainage channel, so that there is drainage between and through the lakes (fig. 6). The outline of the lake at this stage is very irregular because of the complex combination of lakes. The simple circular outline of the original lakes is greatly modified in places. The lakes are flooded and drained repeatedly as the level of the main river fluctuates. Natural levees

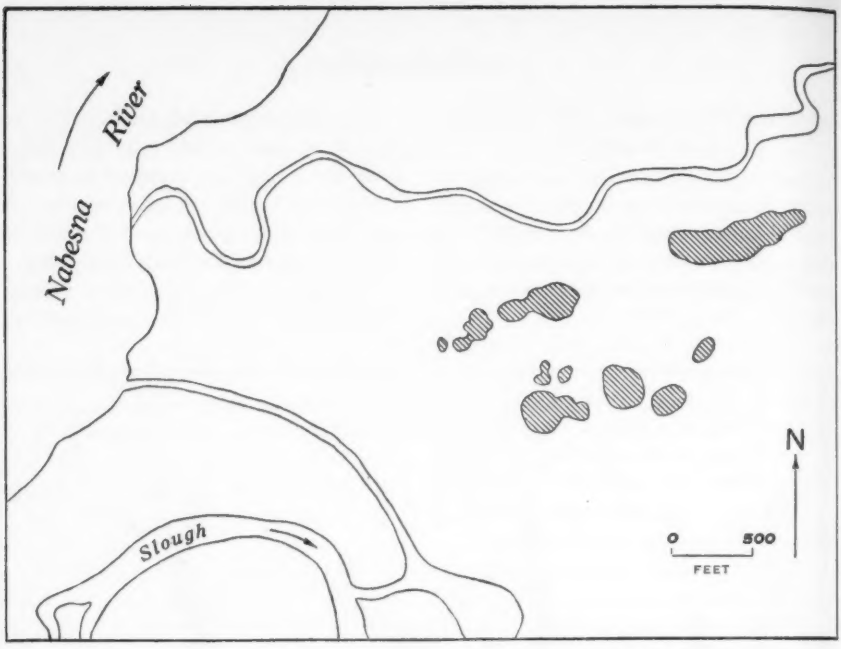

FIG. 4.—Youthful stage of cave-in lake (cross-hatched), marked by simple circular pattern

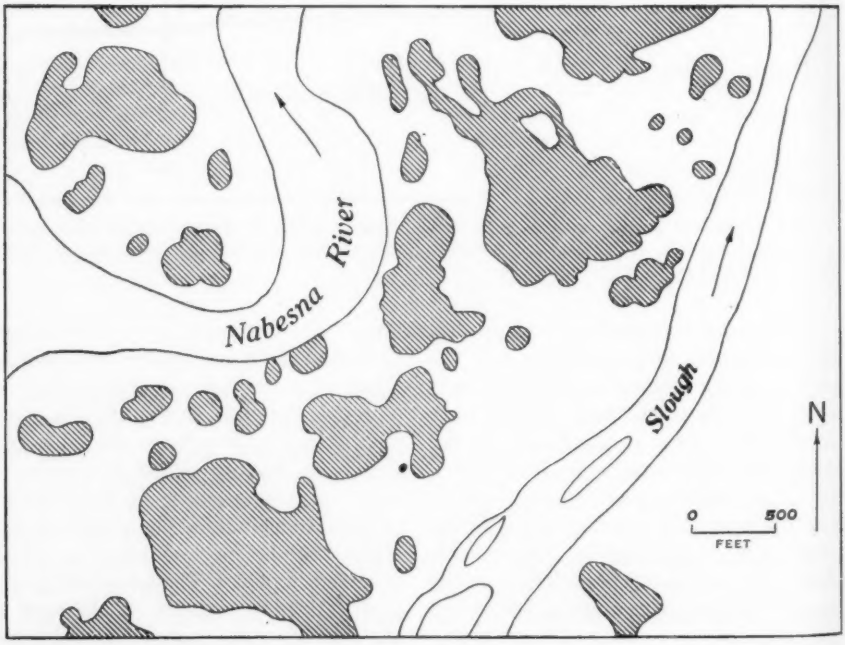

FIG. 5.—Early mature stage of cave-in lake, showing coalescence of many small lakes to form larger lakes (cross-hatched). Note "scalloped" borders. Many youthful, circular cave-in lakes are also present.

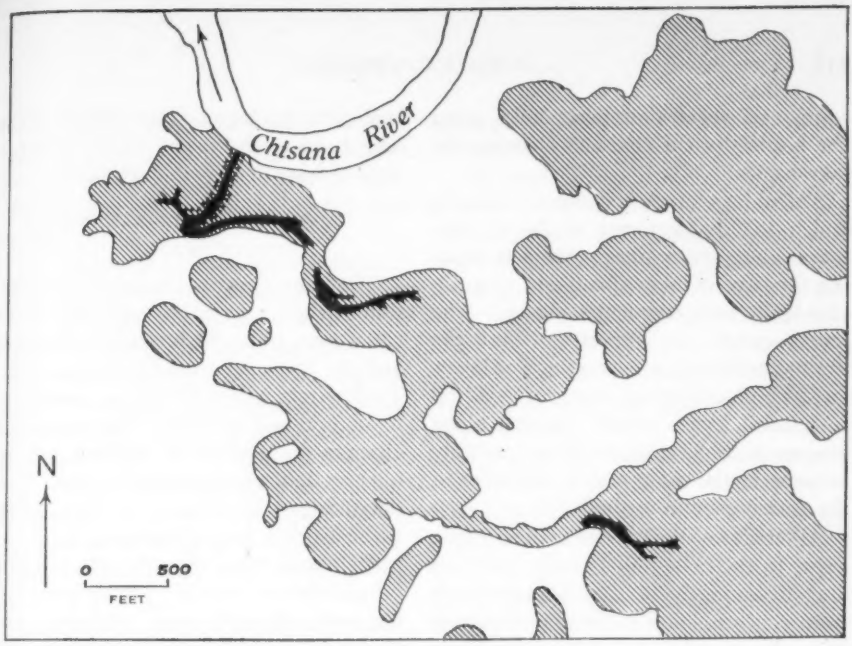

FIG. 6.—Late mature stage of cave-in lake (cross-hatched) showing integration of drainage channels (heavy black) through lake basins, and incipient natural levees (stippled) forming along channels.

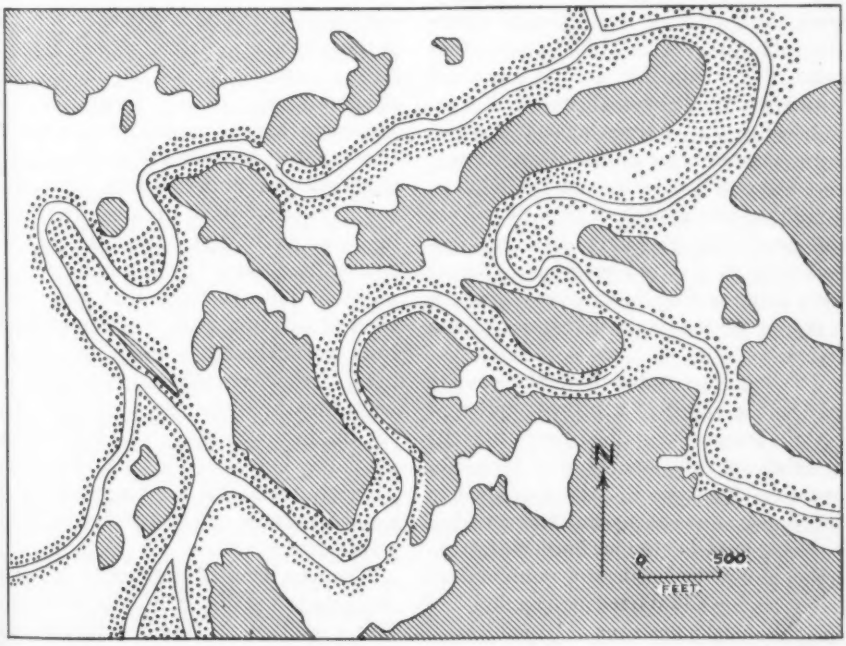

FIG. 7.—Old age stage of cave-in lake, showing segmentation of lakes (cross-hatched) by natural levees (stippled).

form, and vegetation takes hold along the borders of the channels crossing the lake basins.

The old-age stage is defined as that in which the development of the natural levees along the drainage channels crossing the cave-in lakes effectively separate the lakes into segments (fig. 7). The levees create the impression that the drainage channels are avoiding the lakes. In some places caving has proceeded up to natural levees already present along streams and has stopped there, probably because of the more stable character of the frozen ground in the levee.

All stages of the cave-in lake sequence occur in the floodplains of the Nabesna and Chisana rivers, and a progression from youthful lakes in the upper parts of the valley to old-age lakes in the lower parts of the valley was noted. The floodplains are almost free of cave-in lakes above a point approximately 9 miles from the mouth of the Nabesna River. Immediately downstream from that point the floodplains are pock-marked with a multitude of small incipient cave-in lakes (fig. 4). Larger lakes and aggregates of lakes representing the early mature stage of development were found at a point approximately 6 or 7 miles from the mouth (fig. 5). Lakes of the late mature (fig. 6) and old-age stages (fig. 7) were found farther downstream, near the junction of the Nabesna and Chisana rivers.

It should be noted that the cave-in lake is the result of a process and that certain features described here are characteristic of only one type of lake. For example, the type of lake described in this paper starts at a point and proceeds outward to form circular borders. In contrast, along the borders of many oxbow lakes, caving has started along a line, and the oxbow lake has been enlarged irregularly. The scalloped characteristic of the lake borders, however, seems to be a typical feature even in such lakes.

RECESSION OF THE BANKS OF CAVE-IN LAKES

The most direct evidence of the recession of the banks of cave-in lakes is the tilted trees along the borders of the lakes and the drowned trees in the lakes (fig. 3). The rate of retreat of the banks can be determined by noting the progressive changes in the trees affected. A sequence that was commonly observed is diagrammed in figure 3. The undisturbed spruce trees growing on the floodplain stand vertically. As the thawing of permafrost in the banks proceeds, the mat of vegetation, including the shallow, spreading roots of the spruce trees, is undermined and subsides, causing the trees to tilt toward the lake. In the tilted position new growth, growing vertically, forms an angle with the rest of the trunk, as indicated at *A* in figure 3. As the caving progresses beyond the tree, the mat of vegetation and roots again assumes an approximately horizontal attitude but at a lower altitude, so that it is submerged under a foot or two of water. If the roots of the trees are locked in a relatively tight vegetal mat, the tree is tilted toward its originally vertical position. Thus the part that grew while the tree was in a tilted position is tipped from vertical and is tilted toward the bank. Growth continues, and again the new growth, mounting vertically from the tip, forms an angle with the part immediately below, as shown at *B* in figure 3. Such trees can be described as S-shaped because of the two bends in opposite directions.

The first bend, *A* in figure 3, indicates the time in the life of the tree at which it first was tilted. At this time the tree was

at the top of the cave-in bank. The second bend, *B* in figure 3, represents the time at which the base of the cave-in bank reached the tree and the tree was righted.

The number of years that have elapsed since those two events can be determined by counting the internodes from the top of the tree down or by counting the number of growth rings in cross sections of the tree at the bends. The distance that the banks have retreated can be determined and correlated with the elapsed time indicated by the tree growth by measuring the distance from the tree to the base of the bank and to a point on the bank where initial tilting of other trees has begun.

Calculations were made for 15 trees on two lakes. These indicate rates of retreat ranging from 2.3 to 7.5 inches a year. Most of the trees bordering the lakes show but one tilting, that is, toward the lakes. Apparently, the vegetal mat does not remain intact under all the trees, so that, after tilting a certain amount toward the lakes, some trees either fall or at least are not righted after the bank has retreated beyond their position.

The retreating bank is not a simple declivity at all places; indentations and protuberances are common. Small drainage channels develop on the permafrost table along the lake borders at some places. Tributaries branching from these channels were in places nearly parallel to the bank of the lake. Warm meteoric water that flowed in these channels melted the underlying permafrost, and, as it thawed, the trees on either side were tilted toward the channel. Thus some trees on either side were tilted away from the lake and toward the mainland. Such orientations commonly are retained after the trees have been drowned in the lakes. Trees 20 or 30 feet from the banks in some places are tilted in almost all directions.

The vegetal mat containing the roots of trees probably loosens upon saturation with water, so that wind, waves, and heaving of lake-ice, in addition to the thawing of permafrost, can govern the angle and direction of tilt of the trees. Most trees with their roots under water die in less than 10–15 years. Consequently, most of the trees farther out in the lake are dead.

The greatest radius of enlargement that could be identified with relative certainty as having started from a single center is approximately 300 feet. Many radii of approximately this size were noted; but in larger lakes the incorporation of smaller lakes seems to have confused the pattern. At a rate of retreat of 2.3 inches a year, the minimum recorded by trees studied, a lake of 300-foot radius would form in approximately 1,600 years. At a rate of 7.5 inches a year, only 500 years would be required.

ORIGIN OF CAVE-IN LAKES

The beginning of caving such as that found in the floodplains of the Nabesna, Chisna, and Tanana rivers must be preceded by three events: the deposition of sediments, the volume of which changes with freezing and thawing, followed by development of permafrost in those sediments, and, finally, a change in the thermal balance to cause thawing of permafrost.

How permafrost accumulates or how long it has taken to form can only be inferred by indirect evidence. The presence of permafrost near the surface is directly affected by the insulating ground cover. The coefficient of heat-conductivity of dry peat (Muller, 1945, p. 53) is about 0.06, of wet peat approximately 0.50, and of frozen peat about 2.00. The common

sphagnum moss mat probably has similar characteristics. Thus it is possible for heat to be much more easily transmitted outward from the ground in the winter than into the ground in the summer. The result is an accumulation of cold beneath the moss cover.

Whether or not this process can account for great thicknesses of permafrost under present climatic conditions has not been demonstrated. It may be that older permafrost has migrated upward into the new sediments from the rocks upon which the recent floodplain sediments were deposited. This is known to have taken place in placer-mine tailing piles placed on permafrost-bearing ground. It may be that permafrost has formed almost contemporaneously with the deposition of the sediments and has thus been built up, layer by layer.

The point of lowest stable temperature in one hole drilled to a depth of 44.5 feet in the Nabesna River floodplain by the engineers of the St. Paul District was between 19 and 22 feet below the ground surface; and perceptible annual temperature fluctuations took place to a depth of approximately 15 feet over a test period of one year. The temperature below 22 feet was found to grade gradually to a higher temperature at the bottom of the hole. The position of the minimum stable temperature just below the zone of fluctuating temperature is evidence that heat is flowing upward from depths represented by the lower half of the hole to the point of minimum temperature and that the ground is being cooled from the surface downward.

The lakes do not seem to be formed until after the floodplains are covered by vegetation. It is apparently the change from a good insulator, the vegetal cover, to a good accumulator and distributor of heat, such as the lake waters with relatively high specific heat, that enlarges the lake basins. The effect of removal of the vegetal cover has been demonstrated in many places where caving has taken place in ground that had been cleared for construction purposes. In nature the initiation of a lake could result from such an event as the overturning of a tree by wind, with resulting uprooting of the vegetal mat.

The succession of lake stages, ranging from old age near the mouth of the river to the youthful stage, 9 miles upstream, suggests a correlation with the regimen of the river. In this distance the age of the valley ranges from old age at the mouth to a slightly younger age farther upstream. As baseleveling proceeded, fine-grained sediments, which are suggested as a controlling factor in cave-in lake development, were deposited farther and farther upstream. The earliest deposits of fine material were the first to be covered with a vegetal cover that would insulate the deposits and make possible the formation of permafrost. Thus the conditions necessary for the formation of cave-in lakes would be met first in the oldest part of the valley, and the stages in the lake cycle would range upstream from older to younger in proportion to the degree of adjustment of the river and the vegetal cover on the floodplain.

RELATED CONSIDERATIONS

A few of many conditions for which conclusions or information were not obtained during this investigation but which warrant study are: first, the possibility that permafrost forms under the cave-in lake basins after they have been drained and a vegetal cover re-formed; second, the possibility that, if permafrost does form under the old cave-in lake basins, a new sequence or cycle of caving is begun; third, the possibility of identi-

fying "fossil" cave-in lake features in areas now south of the zone of perennially frozen ground; fourth, the possibility of recognizing additional physiographic changes due to the widespread formation of permafrost, as, for example, the heaving of ground as contrasted with caving.

SUMMARY

1. Cave-in lakes result from the thawing of permafrost in material which occupies less volume when thawed than it does when frozen. These conditions limit the development of cave-in lakes to the zones of permafrost and principally to situations in which the ground is composed of fine-grained sediments, as in the floodplain deposits of the Nabesna, Chisana, and Tanana rivers. Cave-in lakes are, therefore, a key identifiable in aerial reconnaissance for delimiting ground which slumps when permafrost is thawed.

2. Cave-in lakes possibly form as a result of a break in the insulating groundcover of vegetation, and their perpetuation and enlargement is a result of the accumulation and distribution of heat by the waters in the cave-in lakes.

3. A sequence of development which can be divided into four stages was recognized. The youthful stage is characterized by circular lakes a few hundred feet in diameter. In the early mature stage the lakes have joined to form aggregates of lakes having "scalloped" shoreline patterns. The late mature stage is reached when an integrated drainage has formed between and through groups of lakes. The old age stage is typified by the predominance of natural levees that have formed along the drainage channels cutting the lakes, thus dividing the lakes into sections. In the old age stage the channels have the appearance of "avoiding" the lakes.

4. S-shaped trees are characteristic of cave-in banks under certain conditions and were used as time gauges in calculating the rate of retreat of banks.

5. The rate of retreat of cave-in banks was found to be between 2.3 and 7.5 inches a year. Ages ranging between 500 and 1,600 years are computed for the lakes in an early mature stage of development.

6. The type of cave-in lake described is one of many manifestations of the cave-in phenomenon.

ACKNOWLEDGMENTS.—Appreciation is expressed to Dr. Siemon W. Muller, of Stanford University and of the Geological Survey, for the introduction to the problem of permafrost. Mr. John Zydik acted as topographer and assistant during this study. Without the cooperation of the Air Transport Command and the Alaskan Department of the Army the execution of the project would hardly have been possible. Excellent aerial photographs of the area made by the U.S. Army Air Force were most useful.

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CRATERS AND CRATER SPRINGS OF THE RIO SALADO[1]

E. R. HARRINGTON
Albuquerque, New Mexico

ABSTRACT

The craters and the crater springs are located approximately 8 miles, air line, northwest of the Jemez Indian Pueblo, which is some 45 miles northwest of Albuquerque, New Mexico. They lie on the eastern slope of the valley of the Rio Salado, a tributary of the Rio Jemez, which, in turn, flows into the Rio Grande. The springs rise through faults in the Permian, Triassic, Jurassic, and Cretaceous sediments, which dip steeply to the west from the Nacimiento uplift first described by Herrick (1904). The area is part of the "Ojo del Espiritu Santo" grant, and the springs here mentioned are referred to locally as the "Phillips springs."

Travertine crater springs are not especially unusual. The craters of the Rio Salado, however, are on a very grand scale and show some features that may be unique. The spring area offers unusual opportunity to study such formations. Within an area of 1 square mile there are some forty springs or craters, which show all gradations from incipient formation to complete extinction.

Probably North America offers no better area for the study of travertine springs. It is surprising that the area is so little known to the continent's geologists.

The region was first visited by white men in 1540, when Coronado, the Spanish conqueror, entered the area in search of gold. The springs of the Jemez country, a few miles to the east, were mentioned in the writings of the time; and it was known that the Coronado expedition mined sulphur for gunpowder a few miles to the east. A few years later some other Spanish explorers saw the great crater springs and named one of them "El Ojo del Espiritu Santo," the "Spring of the Holy Spirit." The name has come down to the present time, indicating that the explorers of the early day were definitely impressed by what they saw. In later times the Spanish colonization of the whole watershed of the Rio Salado was administered as one grant from the Spanish crown, and today it still carries the name of the "Ojo del Espiritu Santo" grant on all maps and legal documents.

Following the Mexican war in 1845, the area passed to the ownership of the United States. A year later Abert (1848*a*, pp. 3–130, map; 1848*b*, pp. 417–546, map) made a geological examination of the newly acquired territories and, when traversing the Jemez region, noted the large deposits of travertine. No references were made specifically to the crater spring area until after 1900, when the waters of the Jemez plateau were studied by Kelly (1913, p. 76). Later, in 1929, Clark (1929, p. 30) made a study of the saline springs of the Rio Salado; and two years later Renick (1931, pp. 87–88) carried on a ground-water study of the same area. In 1943 Harrington (1943, pp. 7–12) referred specifically to the crater springs.

The springs and craters all lie west of the Nacimiento uplift. They rise from the Permian "red beds," which dip steeply away from the pre-Cambrian core of the Sierra Nacimiento. The older craters were high up on the sedimentary slope. The spring waters welled to the surface

[1] Manuscript received October 12, 1947.

PLATE 1

A

A, Large travertine cone. This one rises more than 300 feet above its base. It contains a dry crater, 100 feet in diameter and more than 100 feet deep. It was drained by another crater which broke out several hundred feet below it.

B

B, Looking down on the crater which drained the crater shown in the preceding picture. This crater had built itself up to a height of more than 100 feet. This crater flowed until 1926, when it was partially drained by a flowing well drilled a mile away. Vegetation has not yet had time to make an effective attack on this crater, and it has retained its "bald" appearance.

C

C, Close-up of the crater of the preceding photograph. Crater is about 25 feet across and has vertical sides going down at least 80 feet. The water inside the crater now is about 30 feet below the rim.

PLATE 2

A

A, View looking down into the crater of photograph *C*, above. Picture was taken to show structure of the wall.

B

B, Large travertine crater. This cone is at least 200 feet high. The left slope near the bottom shows an active vent which is now draining away the water which once flowed over the top.

C

C, A view of the "Swimming Pool" spring. Crater is more than 60 feet across and 70 feet deep. Crater is nearly circular. Flow from spring is about 10 gallons per minute.

through a fault. All the waters were highly charged with carbon dioxide, salt, and gypsum. At the surface the loss of carbon dioxide caused part of the calcium bicarbonate to be precipitated as calcium carbonate, and travertine rims were built around the spring vents. The water, of course, ran across the lowest part of the rim; and, as it did so, that part of the rim was built up, and the water was forced to seek a new channel across the confining travertine edge. After centuries of such deposition the springs grew into great travertine cones or mounds, with large craters in their centers (pl. 1, *A*). Some of these craters, now completely dry, consist of a great mound of travertine more than 400 feet high. In one of the large extinct craters the central vent has a diameter of more than 100 feet and a

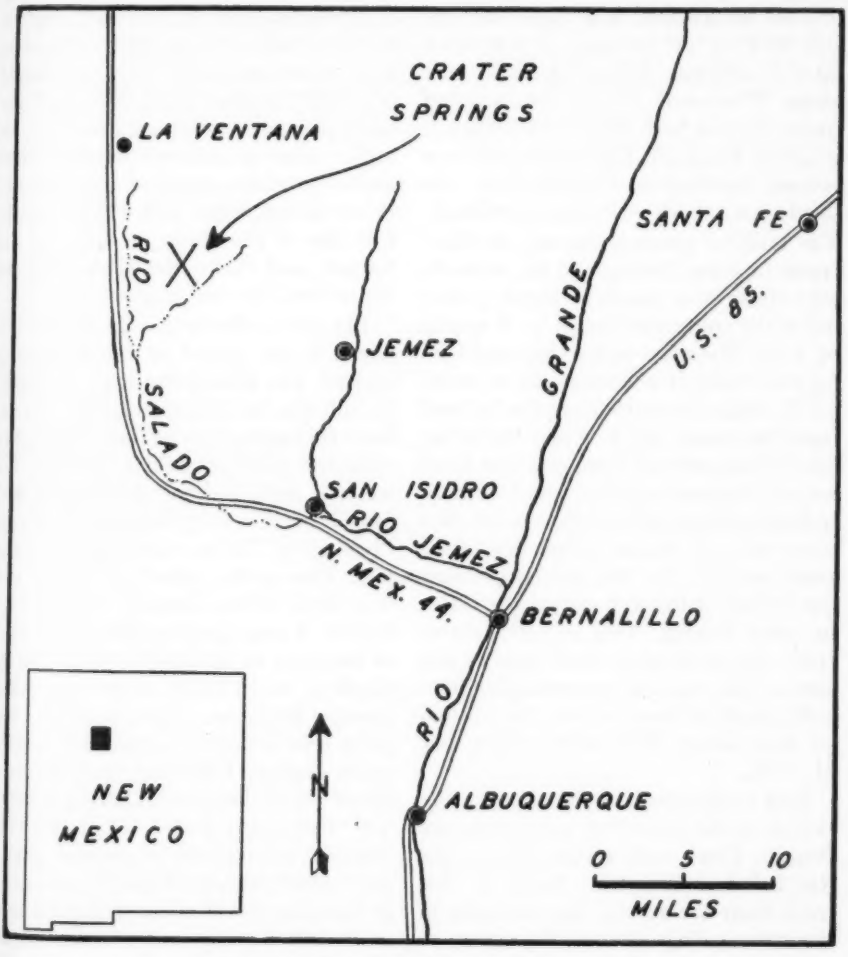

FIG. 1.—Map of the Rio Salado area of New Mexico

depth of possibly 150 feet. After the great craters had built themselves up to such a height, the hydrostatic pressure at the bottom became considerable, and the water broke out farther down the slope. When this happened, the original crater was drained, and a new crater formed at a lower level. In one case three craters show three stages of this drainage process. The top crater was drained by the second one, and the second one was drained by a third. The third one was still building up in 1920. A few years later a well was drilled for gas a mile away. This well struck hot artesian water and has been flowing ever since it was drilled in 1926. The flowing well was several hundred feet lower than the third crater of the series just mentioned. The relief of pressure caused the third crater to cease flowing, and the water in that crater now stands at about 30 feet below the crater rim (see pl. 1, *B* and *C;* pl. 2, *A*). The water in the third and lowest crater was at a temperature of about 70° F., while the water from the hot well issued at about 125° F. From the difference in temperature it appears that there was no common source of water for both well and crater; but it is also evident that some sort of fissure connection must exist between the two sources because the drilling of the well caused the crater to cease flowing. This recently active crater has an irregular vent some 25 feet across. The vent has perpendicular sides and a depth of about 80 feet, the bottom 50 feet being filled with water (see pl. 2, *A*).

Half a mile south of the craters mentioned in the preceding paragraph, the Penasco Creek cuts a channel into the Rio Salado. Along the banks of this creek there are several fine examples of the crater springs. One is a dry crater, 20 feet across and 50 feet deep. Above this crater is a "living" crater spring which has built up a cone more than 100 feet high. Several gallons of water per minute flow from this spring, which is extremely salty and heavily charged with carbon dioxide. The crater vent is only about 10 feet across, but a sounding line was sent down more than 50 feet before encountering any obstruction. Despite the extreme salinity of the water, some hardy salt grasses grow around the crater vent. A quarter of a mile farther up the canyon of the Penasco Creek there is another large travertine crater built to a height of possibly 200 feet (pl. 2, *B*). This crater has twin vents, which are small and not unlike those of geysers. In one of these vents the water stands at about 15 feet below the top. Some 50 feet below, on the east side of the crater, a new vent has formed, and this outlet is draining the water from the vent above.

But half a mile farther up the Penasco Creek is the largest of the still active springs. The flow is less than 10 gallons per minute. Analysis shows that the water from this spring carries more than seven thousand parts per million of solids. The water is salty and heavily charged with carbon dioxide, large bubbles of this gas "boiling up" in the center of the crater lake. This spring crater is an almost perfect circle, with a diameter of more than 60 feet. A sounding line showed the sides of the crater to be almost vertical and the depth to be in excess of 70 feet. Algae growing in the water give it a dull gray-green color sufficient to make a foot of the water opaque. The water temperature is about 70° F. This crater spring is called the "Swimming Pool" (pl. 2, *C*). The name is derived from its general appearance rather than because of its desirability as a place to swim (the writer did swim in it, but he does not recommend the procedure as being safe).

I have seen many travertine deposits and have spent some time in study in Yellowstone Park. I believe that the crater springs of the Rio Salado show phenomena that are not surpassed elsewhere. The great craters are only a mile or two away from a paved road and less than 50 miles from New Mexico's largest city. Even so, the craters are not well known and are seldom visited. This should not be so, and I wish to call the attention of scientists to the opportunities for study presented by the crater springs of the Rio Salado.

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A PRELIMINARY REPORT ON VERTEBRATES FROM THE PERMIAN VALE FORMATION OF TEXAS[1]

EVERETT CLAIRE OLSON
University of Chicago

ABSTRACT

Field work during 1946 and 1947 has produced a moderately extensive fauna of fish, amphibians, and reptiles from the Vale formation of Knox County, Texas. The youngest terrestrial vertebrates previously known from the Texas Permian are of Arroyo age. Aerial photographs were used successfully in exploration and as a basis for accurate indexing of localities.

The vertebrates occur exclusively in channel conglomerates laid down in moderately evenly bedded red and green sands and clays. The environment appears to have been one of moderate rainfall, with extended dry periods interrupted by torrential rains.

Dimetrodon and *Diplocaulus* occur with the greatest frequency. Xenacanth sharks, dipnoans, gymnarthrids, lysorophids, diplocaulids, captorhinids, and various pelycosaurs make up much of the fauna. A preliminary survey indicates that the Vale fauna was derived from the Arroyo fauna, with the addition of a few new elements. A well-developed flora is preserved but is as yet unstudied.

INTRODUCTION

During the summer of 1946 a field party under the writer's direction located vertebrate-bearing beds in the upper part of the Vale formation of the Clear Fork Permian, in Knox County, Texas. Extensive collections of vertebrates have been obtained from the Clyde and Arroyo formations of the Clear Fork group during a period of some seventy years, but all attempts to find terrestrial vertebrates in the Clear Fork formations higher than the Arroyo had been unsuccessful prior to 1946. Aerial photographs, used for preparation of detailed maps (fig. 1) and for reconstruction of the paleogeography, plus a measure of good fortune, made the new discoveries possible. Photographs aided in suggesting that exploration of channel deposits would be most profitable and in plotting routes through the rough country; chance prompted the establishment of the base camp on the only one of several equally inviting localities which has as yet shown any potentiality for production.

A small quarry, which yielded several specimens, was opened in 1946. In the spring of 1947 adjacent deposits were studied. At present, producing beds are known to occur in a north-south band about 1 mile wide and about 8 miles long (fig. 2). A moderately extensive fauna, consisting of fish, amphibians, and reptiles, has been obtained. The fauna has the general cast of that from the Arroyo but differs from it in a number of respects. Associated is a rather extensive flora, as yet unstudied, which should prove to be of considerable interest.

LOCATION OF THE DEPOSITS

The vertebrate-yielding beds of Vale age extend northward about 8 miles from an area located along the southern margin of the breaks of the South Wichita River, 4 miles north of Vera, Texas, on the Vera-Gilliland road in Knox County, Texas. The northernmost exposures yet visited lie along the southern margin of the breaks of the North Wichita River. Between these two areas occur exposures in scattered patches in the valley of the South Wichita River and along the northern margin of its valley (fig. 2).

The productive outcrops are shown on

[1] Manuscript received November 15, 1948.

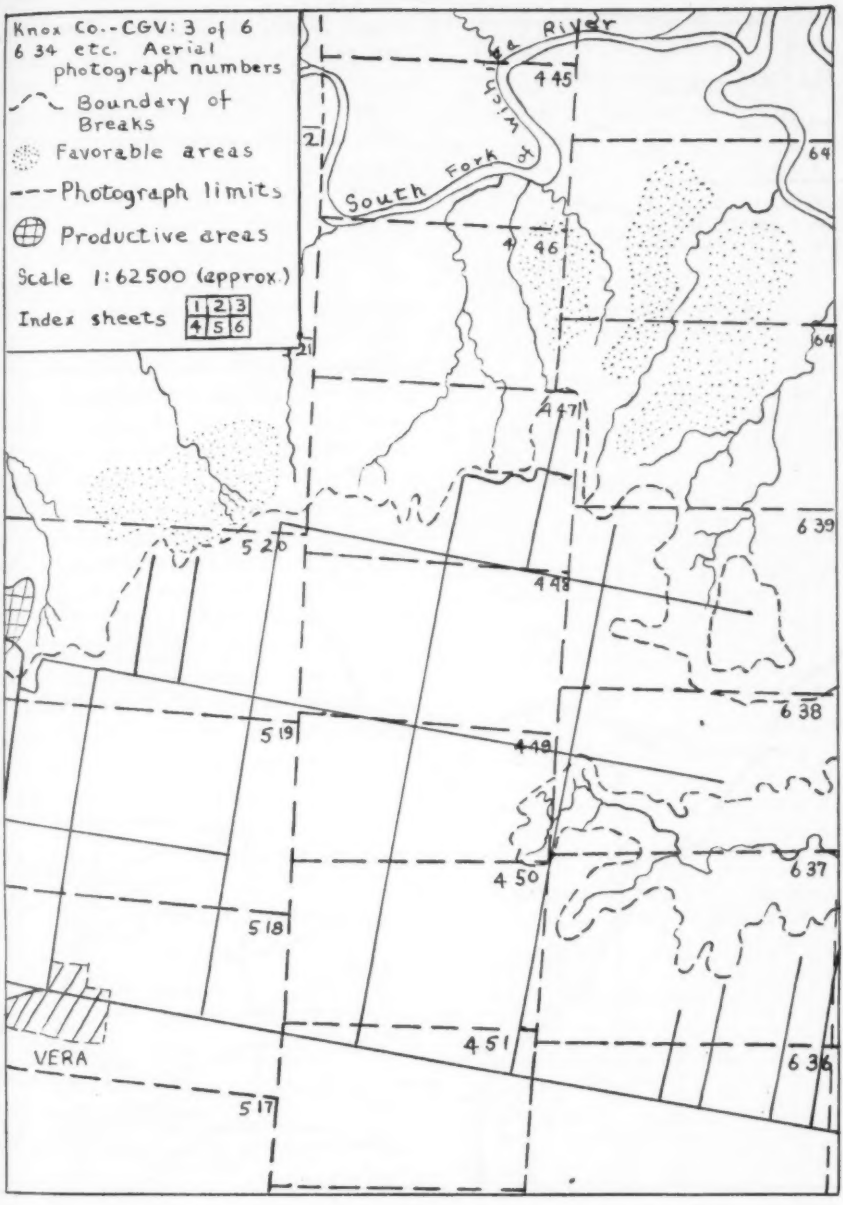


FIG. 1.—An example of the type of map prepared from aerial photographs for field reconnaissance. Reduced from original scale of approximately 1:62,500.

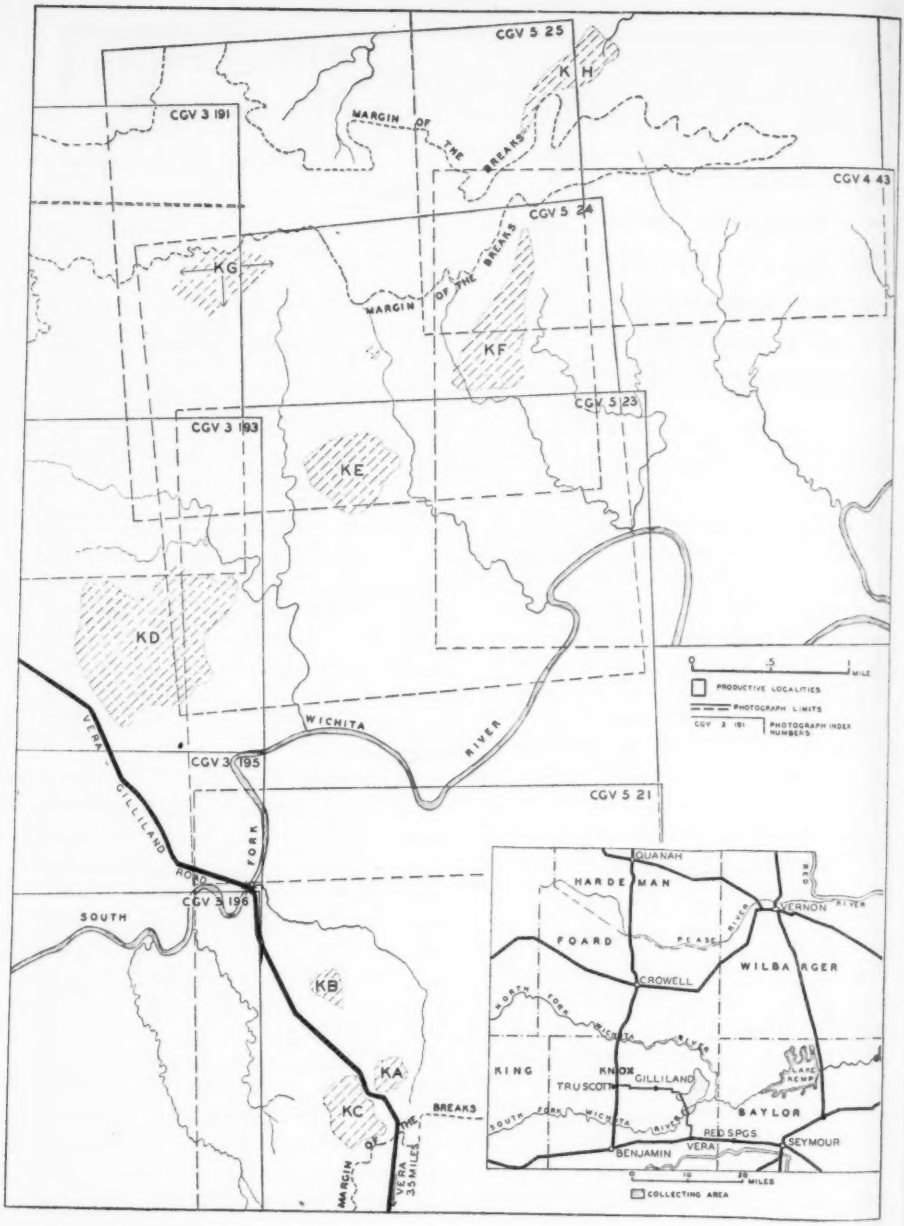


FIG. 2.—Map of collecting area in Knox County, north central Texas, based on aerial photographs. *KA*, *KB*, etc. indicate localities from which fossils have been obtained. Inset map shows the position of collecting area relative to adjacent counties.

aerial photographs of the United States Department of Agriculture of Knox County, *CGV 5 21–25* and *CGV 3 191–194*, as keyed in figure 1. For purposes of reference, each locality is designated by two letters. The first letter, *K*, indicates location in Knox County, to distinguish localities from those in other counties. The second letter distinguishes each locality from others in Knox County. The second letters have been entered in the order in which the localities have been discovered and have no other significance. Each lettered locality may be located precisely by the use of photocoordinates. In the system employed, the locality is defined by three or four limiting points, and, if needed, a roughly central point is also designated. Spot localities of important sites are also noted. All co-ordinates are measured in inches from the lower left-hand corner of the photograph with the *X*-axis entered first and the *Y*-axis second. Small localities are expressed to $\frac{1}{100}$ of an inch which, on 1:20,000 photographs, locates a point within a circle of about a 17-foot radius. Locations of productive areas visited to date are as follows:

KA South wall of valley of South Wichita River east of Vera-Gilliland road

Photograph	CGV 5 20
Centered at	3.2–6.9
Individual localities	3.2–7.1*
	3.3–6.85†
	3.2–6.77‡

* "Bone bed."
† "High channel."
‡ "West channel."

KB Valley of South Wichita River, south of river and east of Vera-Gilliland road

Photograph	CGV 5 21
Centered at	2.55–4.9
Triangular area limited by	2.1–5.1
	2.5–5.1
	2.6–4.9

KC South walls of valley of South Wichita River, west of Vera-Gilliland road

Photograph	CGV 5 21
Roughly rectangular area limited by	3.7–3.8
	3.1–3.2
	2.5–2.7
	2.2–3.2

KD Valley of South Wichita River, north of river and east of Vera-Gilliland road

Photograph	CGV 3 193
Centered at	6.8–4.8
Bounded by irregular lines following outlines of breaks between	8.3–3.5
	7.3–3.5
	5.5–5.8
	6.3–3.1
Individual localities	6.4–5.2§
	7.18–4.22‖

§ "Quarry locality."
‖ "Weathered-boulder locality."

KE Valley of South Wichita River, north of river and east of Vera-Gilliland road

Photograph	CGV 5 24
Centered at	3.5–4.1
Roughly rectangular area limited by	4.5–4.3
	3.6–4.8
	2.7–4.3
	3.6–3.4

KF North wall of valley of South Wichita River, east of Vera-Gilliland road

Photograph	CGV 5 24
Roughly triangular area limited by	7.4–8.4
	5.6–5.7
	7.0–5.6

KG North wall of valley of South Wichita River, east of Vera-Gilliland road

Photograph	CGV 5 25
Centered at	2.0–4.8
Precise limits not as yet defined	

KH Southern margin of valley of North Wichita River

Photograph	CGV 4 41
Strip ½ mile wide from	1.9–3.7 to 3.2–4.6
Limits not fully defined as yet	

This type of designation has proved invaluable in the field. Each locality, of

course, appears on more than one photograph; the practice is to cite the photograph upon which the exposures are best shown. The system has been applied in Baylor County as well, and, as previously known localities are visited, photo-index designations are given. Some twenty localities have now been so designated. With this system, "lost localities" should become a thing of the past, and data for stratigraphic work will be much more exact.

GEOLOGY

AGE OF THE BEDS

There is little in the immediate vicinity of the vertebrate-bearing strata which has any obvious bearing upon their exact age. The Lueders limestone crops out about 20 miles to the east, and upper Clear Fork marine beds cap the hills in western Knox County. Between these limestones no definitely marine beds are encountered. As yet, neither the vertebrates nor the plants have proved definitive within the limits needed, and no invertebrates have been found. Robert Roth, of the Humble Oil and Refining Company of Wichita Falls, Texas, believes that surface and subsurface data show that the beds in question are part of the "Bullwagon" member of the Vale formation. This places the section high in the Vale, just below the Choza.

All fossils have come from rocks which were deposits in channels cut in rather evenly bedded clays and sandstones. The channel deposits are, however, essentially contemporaneous with the beds in which they lie, as discussed in following sections.

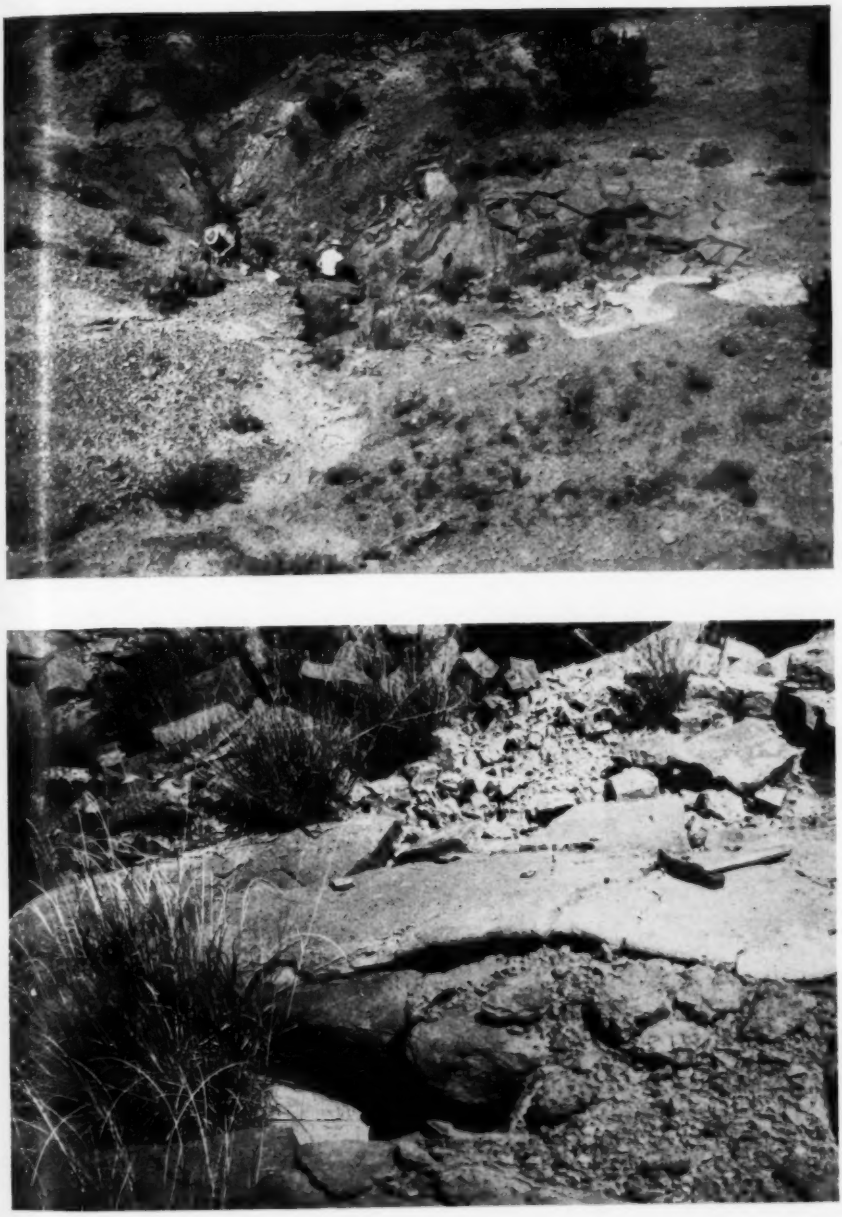
NATURE OF THE BEDS

Fossil-bearing beds are exposed along the steep walls of the South Wichita River Valley, in scattered outcrops on the floor of the valley, and along the south wall of the valley of the North Wichita River. Exploration has not been carried across the valley of the North Wichita, but it appears probable that fossiliferous beds exist along the northern margin of this river. Permian beds form the floor of the South Wichita Valley, but along the margins they are capped by indurated Pleistocene sands and gravels with thicknesses ranging up to 30 feet.

The Permian beds may be divided roughly into two types: (1) widespread, rather evenly bedded red and green clays, sands, and fine conglomerates and (2) linear channel conglomerates.

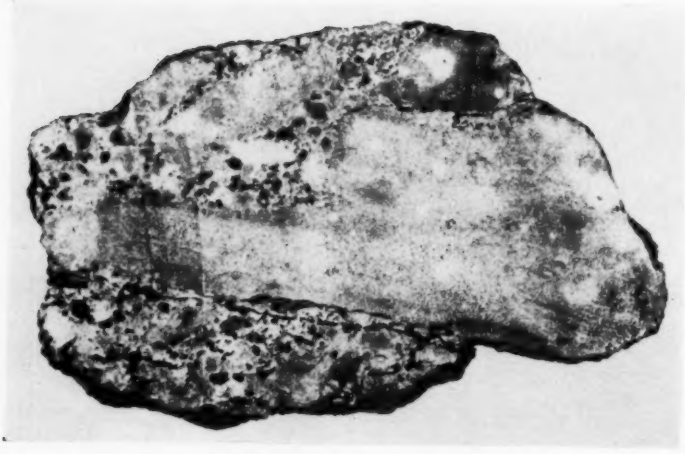
Exposures of clays, sands, and fine-bedded conglomerates extend for several miles up and down the valley of the South Wichita River. To the east they gradually change in character to grade into typical Arroyo beds around Lake Kemp in Baylor County. Their western extension has not been studied; but it is known that there is an increase in the regularity of the bedding, a reduction in the amount of conglomerate, and gradation into the brackish and marine phases of the Choza, in which primary layers of anhydrite and limestone are well developed. The strata have been studied in some detail for about a mile to the east and west of the vertebrate-bearing beds. Within this distance they are relatively constant and, except in the immediate vicinity of the channel conglomerates, are moderately evenly bedded and include members with considerable lateral continuity. As the channel zone is approached, bedding becomes less regular, and dips up to about 12° are encountered. Gypsum is present in irregular masses in the bedded clays and sands and in dikes. A few thin, horizontal layers of fibrous gypsum, with fibers at right angles to the bedding, have been encoun-

PLATE 1



Two views of outcrop of channel deposits at "bone bed" of locality *KA*. *Upper view:* Full extent of outcrop, quarry under ledge in left foreground. *Lower view:* Margin of channel showing rounded lateral edge of conglomerate.

PLATE 2



Section cut through typical sample of red, channel-fill conglomerate

tered. Most, if not all, of the gypsum appears to be secondary; its source apparently was anhydrite beds not now exposed in the area. Primary beds are exposed farther to the west, in the breaks north of Benjamin, for example.

It is the beds to the west which must be explored if vertebrates from still higher Permian formations are to be found in the region. The fact that these are evenly bedded and rich in anhydrite, coupled with the fact that the evenly bedded rocks in the locality under consideration have failed to produce vertebrates, makes prospects rather poor. It seems fairly certain that only channel deposits will be fossiliferous. Reconnaissance studies to date have failed to locate channels in the higher beds.

The channel deposits of the area under discussion in this report, although limited in extent, are of prime interest, since they contain all the vertebrate specimens thus far discovered. The channels are randomly spaced throughout a 100-foot section. The lowest exposures occur on the valley floor in tributaries of the main channel of the South Wichita River not more than 10 feet above river level, and the highest occur directly under the Pleistocene. Several levels of channels have been witnessed, one above the other, in a single exposure. No case in which one channel cuts another has been observed. There appears to be no real faunal difference between the lowest and the highest channels, and, since indications of rapid sedimentation are abundant, age differences appear to be insignificant.

All channel deposits are conglomeratic and distinct from the adjacent beds. They tend to be more resistant to weathering and erosion than are the clays and sands, and they form escarpments and falls and rapids in the intermittent tributaries of the main river (pl. 1). The deposits are distinctly linear, and individual channels have been traced for as much as a mile along meandering courses. Although individual channels are randomly oriented, the general trend of the system of channels is north-south.

The channel-fill is largely clay-pebble conglomerate, with pebbles ranging from a few millimeters to about 8 cm. in diameter (pl. 2). Rounding of the pebbles is uniformly high, but sphericity is varied. There is little vertical variation except near the top of a few channels. The coarsest materials tend to lie at the center of the channel, whereas the marginal parts are predominantly sand or clay with fine, scattered pebbles. Some channels have, in addition to the clay pebbles, fragments of gypsum. Some of these appear to have been developed in openings in the porous conglomerate after deposition of the channel-fills, but others show rounding and wear, which suggest that they are clastic.

In cross section the channels are characteristically lenticular, with convex surfaces above and below. The lateral margins terminate rather abruptly in clearly defined edges, which show no continuity with adjacent beds (pl. 1, lower, and pl. 2). This pattern holds for all major channels and for the majority of small ones; but a few, particularly those which form lenses in sandstone, are less regular and grade laterally into the even beds. The bases of the channel deposits do not grade into the underlying beds, and the tops are commonly distinct. In a few instances, however, the channel conglomerate grades upward into a sandstone which is continuous with the lateral beds.

The coloration of the channels appears to have significance. Channels composed entirely of red or of green sediment have been encountered; much more com-

mon, however, are those in which the center portion is red and the lateral parts are green. The transition is accomplished by an increase in green patches, which occur in some cases even in the center of the channels, until they become dominant and at the extreme margins replace the red entirely. The explanation of color variation is not clear as yet. It is possible that the transition from red to green is due to greater reduction of the lateral portions of the channels, if it is assumed that the primary color was red. On the other hand, the original deposits may have been green, and the red central portions could be due to oxidation of the coarser center parts of the channels. The evidence at hand from preliminary studies suggests that the first interpretation is correct, but the data are by no means conclusive. In channels which are partly red and partly green the original deposition cannot account for the arrangement of materials of the two colors, so that a postdepositional factor clearly was in operation. Megascopic plant remains occur in both the red and the green phases of the channels and have not accomplished notable reduction in the portions which have remained red. Bacteria may have been an important factor, but there is no positive evidence that this was the case.

The relation of the color to the vertebrates is most important. With one exception, all specimens have come from the red phases of the channels. No specimens have been found in the completely green channels, but some bone was encountered in the fine, green lateral phase of a channel in locality *KF*. Preservation of these specimens is good, and whatever changes may have taken place to produce the green color appear to have had no important effect on the bones. That the absence of bones in the green sediments is due to the reduction which altered the red deposits to green is an inviting hypothesis and, except for the one occurrence of bone in green sediment, is in accord with the known facts.

ENVIRONMENT OF DEPOSITION

A reconstruction of conditions at the time of deposition appears to be possible on the basis of the information now at hand.

The channels are evidence that a rather large, braided stream passed north or south over the area in a valley of considerable width. The region must have had a moderately high annual rainfall to support the fauna and flora which have been encountered. The total rainfall was perhaps not greatly different from what it is today, and the temperature may have been quite similar, with possibly less seasonal variation. The rains, however, appear to have been periodic and torrential in character, for it is difficult to account for the deposition of the clay-pebble conglomerates in channels under any other interpretation. During a dry period it would seem that little or no water flowed through the area and that silting in the final stages of flood and shifting of dry sediment by wind action obliterated much of the drainage pattern developed in the preceding rainy period. Were this not the case, it would be reasonable to suppose that earlier channel deposits would be cut by subsequent channels, but no case in which this has occurred has been noted.

During the dry periods aquatic life must have been limited to whatever rain pools, ponds, or small lakes may have been present. The lungfish may have survived by burying themselves in the mud, much as they do today; and there is no proof that the amphibians may not have

behaved similarly. The principal amphibians are *Diplocaulus* and *Lysorophus*, one apparently rather skatelike in shape and the other wormlike. With the onset of heavy rains, floods appear to have gouged out channels which bore little or no relationship to former channels and, with rapid drop in velocity as the rains ceased, to have deposited clay, cut from their banks, as pebbles in a fine matrix of sand and clay. During late stages of flood, as the current slowed and the water began to recede, even beds of sand and clay were deposited on the floodplains and apparently over the channels themselves. This cycle of aggradation appears to have been repeated many times during the deposition of the beds under consideration.

THE FAUNA

Preparation of the specimens collected in 1946 and 1947 is proceeding slowly; and, since it will be some time before a comprehensive report can be issued, the following preliminary account is felt to be in order. Most generic references must be considered tentative, except where assignments are stated to be definite. Names are witheld from genera which are almost certainly new, pending development of all available material. It is hoped that additional collecting will produce more specimens of problematic genera. All known specimens, with one possible exception, appear to be referable to orders recorded from the Arroyo formation, and in most instances specimens can be assigned to families represented in this formation.

PRESERVATION OF THE SPECIMENS

Almost all specimens have come from coarse channel conglomerates. As might be expected under such circumstances, most of the material is fragmentary. An articulated series of vertebrae of *Dimetrodon* was recovered from the quarry of locality *KA;* and partial vertebral columns of small animals, with ribs and parts of the appendicular skeleton associated, have been found in several other localities. Partial skulls, lower jaws, isolated teeth, and various postcranial elements make up the bulk of the collections. Disarticulation of the skeletons has made association of parts of new genera difficult, and the situation may not be entirely clarified until more complete specimens are discovered.

The bone itself is normally in an excellent state of preservation, and, in spite of the coarse matrix, delicate structures have remained intact. The process of preparation has been complicated by the soft and brittle or waxy nature of the bone. Once the matrix has been removed, however, detailed analyses of morphology should prove possible.

CONSTITUTION AND DISTRIBUTION

A tentative general faunal list of identifiable specimens collected to date from the Vale formation of Knox County is as follows:

Class Chondrichthyes
- Order Xenacanthodii
  - Family Xenacanthidae
    - *Xenacanthus* sp.

Class Osteichthyes
- Subclass Choanichthyes
  - Order Dipnoi
    - Genus undetermined

Class Amphibia
- Subclass Lepospondyli
  - Order Nectridia
    - Family Diplocaulidae
      - *Diplocaulus* sp.
  - Order Micramphibian
    - Family Gymnarthridae
      - Genus undetermined
  - Order Lysorophia
    - Family Lysorophidae
      - *Lysorophus* sp.

Class Reptilia
Subclass Eureptilia
Infraclass Captorhina
Order Captorhinomorpha
Family Captorhinidae
Captorhinus sp.
?*Labidosaurus* sp.
Infraclass Synapsida
Order Pelycosauria
Suborder Sphenacodontia
Family Sphenacodontidae
Dimetrodon sp.
Suborder Edaphosauria
Family Edaphodauridae
?*Edaphosaurus* sp.
Genus undetermined

There is no real basis for specific differentiation from the Arroyo specimens, but teeth of *Xenacanthus* are highly unsatisfactory for specific determination. Several hundred teeth have been observed in the channel conglomerates.

Class Osteichthyes

Order Dipnoi

Several fragmentary specimens of lungfish teeth have been observed, and two moderately good specimens have been obtained. The occurrences are limited to localities *KD* and *KF*, but this probably has little real significance in view of the small size and fragmentary nature of the specimens. The teeth resemble those of *Gnathorhiza* from the Arroyo but show differences in form and size, which make it probable that they must be referred to a new genus.

TABLE 1

Genera	Localities							
	KA	*KB*	*KC*	*KD*	*KE*	*KF*	*KG*	*KH**
Xenacanthus	×	×	×	×	×	×	×	×
Dipnoan				×		×		
Diplocaulus	×	×	×	×	×	×		×
Gymnarthrid				×		×		
Lysorophus				×		×		
Captorhinus	×	×		?×				
?*Labidosaurus*				×				
Dimetrodon	×	×	?×	×	×	×	?×	
?*Edaphosaurus*	×			×		?×		
Edaphosaurid		×		×				×

* Not fully prospected.

Ten distinct genera are recorded in this faunal list. In addition, there are specimens of amphibians and reptiles which cannot be given family reference as yet and which are distinct from the listed genera. The recorded genera are distributed throughout the various collecting localities, as shown in table 1.

Discussion of the Fauna

Class Chondrichthyes

Family Xenacanthidae

This group of fresh-water sharks is represented throughout the area by teeth and fragments of calcified cartilage. The teeth are uniformly small and resemble those in the Arroyo formation.

Class Amphibia

Subclass Lepospondyli

Order Nectridia

Family Diplocaulidae

Diplocaulus is the most abundant tetrapod in the area and has a frequency almost double that of its nearest rival, *Dimetrodon*. There is no doubt concern-

ing the identity of the genus. Several good skulls, parts of skulls, and fragments of postcrania have been obtained. At present it is not feasible to attempt specific determination because of the confusion which exists concerning the Arroyo diplocaulids. The writer is now engaged in an analysis of the growth and variations of the Arroyo specimens of *Diplocaulus;* and, when this study has been completed, it may be possible to place the Vale diplocaulids accurately. At present it is impossible to determine whether or not more than one species is present in the Vale.

The skulls are of moderate size, with a midline length of from 80 to 100 mm. They exhibit mature growth patterns, in contrast to skulls of similar length from the Arroyo. The dermal roofing of the skulls is very thin. These features suggest that the Vale specimens are specifically different from those of the Arroyo; but the criteria are at present insufficiently tested to permit absolute interpretation.

Order Micramphibia

Family Gymnarthridae

Fragments of skulls and vertebrae interpreted as gymnarthrids have been found at localities *KD* and *KF*. The identification has been based primarily upon teeth and vertebrae, since no adequately preserved skulls have as yet been found. Generic identification is impossible on the basis of known specimens.

Order Lysorophia

Family Lysorophidae

Lysorophids appear to be quite common in the area, but the only remains which can be definitely assigned to the family are series of vertebrae found in clay nodules incorporated in the conglomerate at locality *KD*. No detailed study has been made, but both the general features of the vertebrae and the mode of occurrence strongly suggest the genus *Lysorophus*. There is a wide range of size in known specimens. In the smallest there appear to be as many as ten vertebrae to the centimeter, while, in the largest, vertebrae are several millimeters in length. Most specimens fall within the size range of typical specimens of *Lysorophus* from the Arroyo. Determination of species in this genus is exceedingly difficult, inasmuch as most available material consists of vertebrae. There is no basis for differentiating the Arroyo and the Vale specimens specifically, but there are no positive criteria for assignment to the same species.

Class Reptilia

Subclass Eureptilia

Infraclass Captorhina

Order Captorhinomorpha

Family Captorhinidae

Captorhinus and one specimen which may be tentatively assigned to *Labidosaurus* represent the family Captorhinidae. The best specimen of *Captorhinus* consists of a partial skull and lower jaws, a series of vertebrae, and parts of limb bones. The other specimens are fragmentary. There appears to be no question of generic assignment. The variety of specimens of *Captorhinus* from the Clyde and Arroyo formations of Texas and from Oklahoma has resulted in considerable confusion in the taxonomy of the genus. The Vale specimens fall within the limits of variation witnessed in Arroyo specimens, but it is not possible to make specific assignment until the taxonomy of specimens from the Arroyo has been clarified. The specimen from local-

ity *KD* of the Vale has a median length of about 80 mm., which compares favorably with that of larger specimens from the Arroyo.

The one specimen tentatively referred to *Labidosaurus* consists of a well-preserved snout, including the anterior margin of the orbits. The snout is about 3 inches long and is much like that of *Labidosaurus*, except that the external nares are very large. This character may be sufficient basis for assignment to a new species, but no designation will be made until the captorhinids are thoroughly studied.

Infraclass Synapsida

Order Pelycosauria

Family Sphenacodontidae

Dimetrodon is the only sphenacodont which has been definitely identified from the Vale. This genus is second only to *Diplocaulus* in abundance and has been found as fragments in all localities except *KH* and in quarries in *KA* and *KD*. There is a wide size range in the fragmentary specimens, but that this has taxonomic significance is open to question. All well-preserved specimens seem to belong to a single species. The mature animals were quite large, comparable in size to *D. gigashomogenes* of the Arroyo. No more than fragments of skulls have been found, so that determination must be based upon postcranial elements. The most striking feature of the vertebrae is the exceedingly long neural spines, which are so deeply grooved anteriorly and posteriorly for part of their length that the shafts are nearly separated into lateral halves. Preliminary examination suggests that the Vale *Dimetrodon* is close to *D. gigashomogenes* of the Arroyo. There are differences in the vertebrae which appear to be specifically significant, but it seems probable that the Vale species was derived from *D. gigashomogenes*.

Some of the smaller specimens referred to *Dimetrodon* may well belong to one or more other species, and some fragments may represent other genera. Many of the fragments are so incomplete that identification is difficult.

Suborder Edaphosauria

Family Edaphosauridae

The edaphosaurids of the Vale should offer an interesting series for study when more complete materials have been obtained; but at present they are recognized only from tooth-bearing palatal plates and lower jaws. No trace of the characteristic *Edaphosaurus* neural spines has been found, and this in itself is interesting, since spines are normally abundant in areas where the genus occurs. In view of this, although some of the palatal plates have the characteristic *Edaphosaurus* dental arrangement, there is some doubt that they actually belong to this genus. In addition to pterygoid plates studded with *Edaphosaurus*-like teeth, two large palates with teeth arranged in regular rows have been found. They bear some resemblance to the pterygoid plate from the Arroyo referred tentatively to *Trichasaurus* by A. S. Romer and L. I. Price (1940, p. 423); but generic identity seems improbable, and Romer and Price's reference of the Arroyo plate to *Trichasaurus* is, of course, extremely problematical. There seems little doubt that the large plates from the Vale are edaphosaurid, but more definite assignment is not possible at the present time.

Several partial lower jaws seem to pertain to the edaphosaurid. They are varied in size and may represent more than one genus. None has been found associated with more than a fragment of skull, so

that it has not been possible to determine proper associations.

INDETERMINATE SPECIMENS

In addition to the specimens which have been discussed, a number have not as yet been identified. This has resulted either from exposure in the field inadequate to permit even rough identification or from an inability to interpret affinities on the basis of structures which are visible. Many of the specimens in the former category may prove to be additional representatives of genera already discussed, but those in the latter group may prove to be of considerable interest as new elements from the Permian. Two of particular interest are discussed in the following paragraphs.

Among the most interesting specimens found is a large scapulo-coracoid whose total height is nearly 15 inches. The coracoid area has been badly damaged by crystallization of gypsum within the bone, and preservation of no part of the bone is adequate. Most puzzling is the extremely narrow scapular blade, which has a maximum width of less than 3 inches. The bone is unlike anything known from the North American Permian. It is too large to be associated with any of the genera from the area, except possibly the large edaphosaurid palatal plate. The resemblance to an edaphosaurid scapulo-coracoid is remote at best.

Parts of several small jaws, 3–4 inches long, have been found. The teeth are conical and sharply pointed, suggesting affinities with some primitive sphenacodont pelycosaur. Such an assignment, however, can be considered only as extremely tentative. In addition to the jaws, there are fragments of limb bones and vertebrae, which give further evidence of the occurrence of small, indeterminate pelycosaurs.

SUMMARY OF THE FAUNA

The fauna is interesting in a number of respects; and presumably, as details are revealed, they will add a significant chapter to our knowledge of the Permian vertebrates of North America. Positive knowledge shows a fauna similar to that from the Arroyo but containing a few new genera. Possibly because all materials have come from channel-fills, certain genera which are common in the Arroyo are missing. Nonetheless, the absence of certain genera is striking and may prove of evolutionary and stratigraphic importance. Notable is the apparent absence of rhachitomous amphibians. In the lower formation they are not uncommon in stream-channel deposits, and it seems rather remarkable that such large genera as *Eryops* and *Trimerorhachis* have not been encountered. Another notable absence is that of the large parareptilian genus, *Diadectes*, which is abundant in the Arroyo. It is quite possible that future work will reveal the presence of these and other common Arroyo genera, but present indications are that they did not form a part of the fauna.

No definitely new elements have been added to the lower Permian fauna, unless it be the animal represented by the large, undetermined scapulo-coracoid. In almost every respect the fauna has continuity with that of the Arroyo formation and may reasonably be interpreted as an evolutionary development from this fauna.

NOTES ON THE FLORA

To date, the flora of the deposits has been neglected in large part, since its study was not the primary objective of the work. There is, however, a rather extensive flora present, and it offers considerable promise for future work. Plant re-

mains occur in the channel deposits in direct association with the vertebrates, in green phases of the channels which contain no vertebrates, and in the evenly bedded red and green beds cut by the channels. Many of the plants are preserved as impression only, but in some instances replacement has preserved internal structure. The most common replacing material is hematite. About a dozen plant specimens have been collected, but as yet no study of them has been made.

Most common is a *Calamites*-like plant represented by small to moderately sized stems. Fronds of Filicales or Cycadofilicales are moderately abundant but rarely well preserved. There is some evidence of conifers in strobili and fronds. Evaluation of the flora as a basis for environmental and stratigraphic interpretation must await more extensive collecting and study by an expert in late Paleozoic paleobotany.

ACKNOWLEDGMENTS.—Much credit goes to my field partners in this work, Michael S. Chappars, Roy Reinhart, and Nicholas Hotton III, whose aid in prospecting and collecting made it possible to obtain a good fauna from relatively barren beds in a short time. I also express my appreciation to Mr. Robert Anderson, of the Waggoner Estate, with headquarters at Vernon, Texas, and to Mr. Wallace Nichols, of Dallas, Texas, for granting my parties permission to work upon their respective properties and for extending courtesies which made the work more pleasant and efficient.

REFERENCE CITED

ROMER, A. S., and PRICE, L. I. (1940) Review of the Pelycosauria: Geol. Soc. America Special Paper 28.

A NOTE ON THE ORIGINAL ISOTOPIC COMPOSITION OF TERRESTRIAL CARBON[1]

KALERVO RANKAMA
University of Helsinki[2]

ABSTRACT

The primordial isotopic composition of terrestrial carbon is discussed with reference to astrophysical and geological evidence on the possibilities of fractionation of isotopes. It is suggested that the original isotopic composition of terrestrial carbon corresponds to that found in meteorites, where the C^{12}/C^{13} ratio ranges from 89.8 to 92.0. As is known by earlier investigations, the inorganic processes on the earth tend to concentrate the heavy isotope, C^{13}, whereas the light one, C^{12}, is accumulated by organic processes. The isotopic composition of O, Fe, and Cu, as compared with that of C, in meteorites and terrestrial samples is discussed.

INTRODUCTION

There is a very definite trend in present-day geology and related sciences toward considering the earth as a vast physicochemical system, treating the facts collected statistically and using the results obtained from the study of a number of more or less limited areas on a global scale. Geology, as a science, has decidedly entered a period of "exactization" and today applies the results and methods of the more fundamental sciences: physics, chemistry, and astronomy. Among other things the more recent results in the study of isotopes are now being applied to geology and geochemistry. Wickman (1941) was the first to use isotopes in the study of a geochemical problem. He calculated the total amount of coal and bitumen on the basis of the abundance ratios of the carbon isotopes C^{12} and C^{13}, determined by Nier and Gulbransen (1939) and by Murphey and Nier (1941). Another contribution has been made by the present author in a still unpublished study of the origin of pre-Cambrian carbon. For that investigation all the original C^{12}/C^{13} determinations carried out by Murphey (1941) were made available to the author through the courtesy of Dr. Alfred O. C. Nier. They proved to be of very considerable geochemical interest, and it was found possible to use them as a starting-point for a discussion dealing with the original isotopic composition of terrestrial carbon, which will be presented in this paper. However, it is necessary to consider recent results of astrophysics and geology, which serve as a useful basis for the study of the isotope fractionation.

[1] Manuscript received January 23, 1948.

[2] On leave; at present at the University of Chicago.

ASTROPHYSICAL AND GEOLOGICAL BACKGROUND OF THE FRACTIONATION OF CARBON ISOTOPES

GENERAL REMARKS

Although several determinations of the isotope ratio C^{12}/C^{13} were made by previous workers, the investigations of Nier, Gulbransen, and Murphey referred to above are the first systematic studies of the variation of the C^{12}/C^{13} ratio in different sources of carbon found in nature. They found that the heavy isotope, C^{13}, is concentrated in limestones, whereas carbon of vegetable origin has a preference for the light isotope, C^{12}. The variations in the C^{12}/C^{13} ratio are thus related to the origin of the samples, and Nier and

his associates assumed that the igneous carbons represent the original C^{12}/C^{13} ratio. The opposite conclusion was reached by Wickman (1941, p. 420), who pointed out that, in view of the modern petrogenetic theories, carbon found in igneous rocks could not be considered to prove anything about the original C^{12}/C^{13} ratio. Similarly, he concluded that the meteorites could not supply an answer to this question because of their variation of the C^{12}/C^{13} ratio, which is greater than that found in any other group analyzed by Nier and his co-workers. Wickman finally assumed that diamond showed the original isotopic composition of terrestrial carbon and pointed out that the corrected C^{12}/C^{13} value of this mineral was lower than any found in the meteorite carbons—a fact not at all unreasonable, considering the wide variation in the latter case.

ASTROPHYSICAL BACKGROUND

The very fragmentary information which is collected on the interior structure of the earth is based mainly on the propagation of seismic waves and on meteorite studies. It is commonly believed today that the iron meteorites correspond to the hypothetical nickel-iron core of the earth, whereas the silicate meteorites are thought to be counterparts of the upper layers of the earth's crust, notably the Sima layer. The origin of the meteorites has been a matter of controversy for some time, but, as stated by Paneth (1940, 1946), the evidence is now believed to be overwhelmingly in favor of meteorites' being fragments of a member of the solar system. Similarly, petrological properties of the meteorites point strongly toward their origin by fragmentation of a larger astronomical body, as is stated by Foshag (1941, p. 144). The view that the meteorites are scattered parts of a single celestial body was first expressed more than a hundred years ago by the German astronomer, Heinrich Wilhelm Matthias Olbers. Much trouble was caused by the fact that the most recent age determinations of siderites, carried out by Paneth and his coworkers by the use of the helium method, gave values ranging from less than $0.11 \cdot 10^6$ years to $6{,}800 \cdot 10^6$ years (Arrol, Jacobi, and Paneth, 1942). On the basis of these values they claimed that the solar system cannot be less than $7{,}000 \cdot 10^6$ years old. On the other hand, there is much astronomical and astrophysical evidence indicating that the age of the universe is of the order of $3{,}000 \cdot 10^6$ years, which value was given by Chandrasekhar (1944) and by Shapley (1945). There are, accordingly, two time scales for the universe, and most of the evidence now available seems to be in favor of the shorter. The varying helium ages of the iron meteorites are explained by Bauer (1947) in a recent contribution in which he emphasizes the fact that the high helium contents appear only in the relatively small masses. The explanation offered by Bauer is that cosmic radiation has produced extra helium in the small meteoroids. Nuclear disruptions in which α-particles are among the disintegration products are caused by cosmic radiation. Bauer has also calculated the rate of α-particle formation for a meteoroid, and he concludes that the maximum helium content observed is produced in $3{,}400 \cdot 10^6$ years, which is just half the highest age calculated by Paneth.

It may thus be concluded that the most recent results of the age determination of iron meteorites furnish further proof of the validity of the short time scale. Shapley's (1945, p. 520) opinion is that the evidence of the moment is fairly strong that the planets, the meteorites,

the galaxies, the double stars, possibly the clusters of galaxies, and certainly the expansion of the galaxies in the part of the metagalaxy which can be observed all date back to a time about $3{,}000 \cdot 10^6$ years ago when something momentous happened, or to the zero-hour epoch, t_0, in the expansion of the universe of galaxies.

GEOLOGICAL BACKGROUND

According to Shapley (1945, p. 511), the astronomers see little support for the suggestion that all the planets of our solar system may not have been born together. Shapley also thinks (1945, p. 508) that the necessarily rapid cooling and crustal solidification of small or medium-sized astronomical bodies caused the congealing of the earth's crust at a time when the galaxies were still closely packed together. According to the calculations presented in the previous section, the age of the earth should thus be approximately $3{,}000 \cdot 10^6$ years or, to use the value determined by Bauer for the iron meteorites, $3{,}400 \cdot 10^6$ years.

A new value for the age of the earth, of about $3{,}350 \cdot 10^6$ years, was recently presented by Holmes (1947). This is a revised estimate based on Nier's analyses of the isotopic composition of lead from galenas and other lead minerals of known geological age. The close correspondence between the above value and that given by Bauer for the length of helium production in siderites is, perhaps, more than a strange coincidence. According to Ahrens (1948), the age of the pegmatites of southeastern Manitoba, as determined by the use of the strontium method, is about $2{,}100 \cdot 10^6$ years. Although these pegmatites are evidently the oldest rocks whose age has ever been measured, the surrounding rock complex, by its geological properties, must be still more ancient, although it certainly does not represent the primordial crust of the earth. Certainly, the first crust of our planet is nowhere exposed, and even the oldest rocks thus far encountered must be several hundred, if not a thousand, million years younger than the first patches of solid crust which quite probably were remelted several times after their formation, until a crust of sufficient thickness and permanence surrounded the earth. It may also be possible, as suggested by the present writer (Rankama, 1946), that the upper lithosphere of today is the product of a continuous process of differentiation, whereby the elements peculiar to granitic rocks are carried and concentrated upward, while other elements are pushed back toward the basaltic substratum. Therefore, it is impossible to make any direct determination of the absolute astronomical age of our planet based on the use of geological materials. On the other hand, it is safe to assume that if age determinations were made of the deeper parts of the earth, they would give higher values than those obtained for the superficial parts of the earth. Attention must also be paid to the possibility that changes in the isotopic composition of elements, such as would be likely to affect the results of the age determinations, might take place during the processes outlined above.

It may be concluded from the discussion presented above that present-day evidence favors the coevality and common origin of the earth and the meteorites. Therefore, the discussion on the fractionation of the carbon isotopes which follows is based on the principle of the similarity of meteoritic and terrestrial matter. The uppermost parts of the lithosphere are not as yet known to have a counterpart among the meteorites.

COSMIC ABUNDANCE OF C^{12} AND C^{13}

During the sidereal and planetary life of the elements their isotopic composition is evidently subject to changes, and the present abundance ratios of the isotopes are the result of a long evolution. The primeval carbon, in particular, is thought to possess a C^{12}/C^{13} ratio different from that found in present-day carbonaceous substances.

The presence of the carbon isotopes in class N stars was established by Sanford (1929). Menzel (1930, p. 35) concluded that C^{12} is certainly not more than ten times as abundant as C^{13} in the N-type stars. Fairly convincing evidence of the presence of C^{13} in R stars also was found by Sanford (1932).

The occurrence of the carbon isotopes C^{12} and C^{13} in the spectra of N-type stars was further investigated by Shajn (1942), who found the relative concentration of C^{13} to be between 0.05 and 0.50, depending on the particular N star, or much in excess of the values recorded on the earth. The corresponding C^{12}/C^{13} ratios, calculated from the values given by Shajn, are 19 and 1, respectively. Recently, McKellar (1947) presented tentative values for the ratio C^{12}/C^{13} in fifteen R-type stars. McKellar was able to distinguish at least two groups among the R stars, one with C^{12}/C^{13} equal to 50 or more and another group with a ratio of about 3.4. He also suggested that in the first group the composition of the carbon was, perhaps, not unlike terrestrial and meteoritic samples where the ratio is about 90. It should be pointed out that very strong bands due to carbon molecules and carbon compounds are present in the spectra of the R and N stars. Hence it is assumed that the atmospheres of these stars are reducing because the amount of carbon present therein is higher than that of oxygen. Most of the cooler stars, on the other hand, have oxidizing atmospheres, in which the excess of oxygen permits the formation of oxides.

A summary of the evidence available on the relative abundance of the carbon isotopes C^{12} and C^{13} in stellar atmospheres shows beyond all doubt that there are very pronounced differences in the C^{12}/C^{13} ratio of the N- and the R-type stars. As pointed out by McKellar (1947), this distinction is of interest in relation to stellar evolution and nuclear reactions taking place in the stars. According to Bethe (1939), C^{12} and C^{13} play an important part as catalysts in the nuclear reactions producing helium from hydrogen. Therefore, the stage of the more stable C^{12}/C^{13} ratio cannot be initiated until a phase in the stellar evolution is reached where the possibility of nuclear reactions is excluded.

Furthermore, Bobrovnikoff (1930) has established the presence of C^{13} in comets; and, according to Swings (1943, p. 91), the relative abundance of C^{12} and C^{13} may be different in various comets.

TERRESTRIAL AND METEORITIC ABUNDANCE OF C^{12} AND C^{13}

King (1936) and Jenkins and King (1936) were the first to determine the abundance of C^{13} in a meteorite. Their results, obtained by the use of spectrographic methods, showed no difference in the relative abundance of the isotopes C^{12} and C^{13}. Murphey (1941) analyzed several meteorites, the average C^{12}/C^{13} ratios being published by Murphey and Nier (1941). As to terrestrial samples, the reader is referred to the papers mentioned on page 199. There is, in addition, a paper by West (1945) which deals with the relative abundance of C^{12} and C^{13} in petroleum. The total number of individual C^{12}/C^{13} determinations now available

is, therefore, more than one hundred. The values, a number of which are given as averages, are listed in table 1.

The values of table 1 show that there are systematic differences among the four existing sets of data. The ratios given by Murphey are higher than the previous ones published by Nier and Gulbransen, as was pointed out by Wickman (1941) and by West (1945), whereas the values of the latter are still higher and those given by the present author are comparable to Murphey's figures. As three different mass spectrometers have been used to obtain the values listed in table 1, it is considered appropriate to exclude, in the following, the values given by Nier and Gulbransen and by West, for reasons discussed in a previous paper (Rankama, in press). The remaining values, which were obtained with the same mass spectrometer, are presented in figure 1, the C^{12}/C^{13} ratios being therein grouped according to the origin of the samples investigated.

Starting from the fact established by Nier and Gulbransen (1939) that plants tend to concentrate the lighter isotope, C^{12}, whereas the heavier one, C^{13}, becomes concentrated in limestones, the presence of two groups of carbon, inorganic and organic, can be established.[3] However, neither of these processes seems to be able to lead to a complete separation of the carbon isotopes during the fractionation. In some cases the C^{12}/C^{13} ratios would also seem to be influenced by the presence of both inorganic and organic carbon, as in the case of metamorphosed sediments which may contain graphite deposited initially as a residual mineral, together with carbon of bituminous origin. Likewise, as stated by Murphey (1941), the carbonates deposited from sea water containing decaying humic matter would consist of carbon of lower C^{13} percentage than those precipitated in water free from such contamination. An example of such conditions is actually furnished by the C^{12}/C^{13} ratio in the carbonate from the coal ball (table 1).

[3] Additional evidence that the content of C^{13} in animal tissues is lower than in mineral sources was furnished by Swendseid, Barnes, Hemingway, and Nier (1942).

THE PRIMORDIAL ISOTOPIC COMPOSITION OF TERRESTRIAL CARBON

The position occupied by the meteoritic carbons in figure 1 is of considerable interest. The C^{12}/C^{13} ratio of meteoritic carbon is 89.8–92.0, but that of inorganic carbon is 87.9–90.2, and of the organic group it is 90.3–93.1. The meteoritic carbon evidently forms an intermediate group between the carbons of inorganic and those of organic origin. Therefore, it seems reasonable to assume that the meteoritic carbon does actually show the primordial isotopic composition of this element, in so far as our solar system is considered, that is, at a stage when the cooling excluded further nuclear reactions. Such a conclusion would fit very well into the general picture of the fractionation of the carbon isotopes because, starting from the original C^{12} and C^{13} contents, there are two opposite series of processes, viz., the inorganic processes tending to concentrate C^{13} and lower the C^{12}/C^{13} ratio and the organic ones accumulating C^{12} and increasing the value of the isotope ratio. Similarly, the astrophysical and geological background of the fractionation presented above gives no evidence which would contradict this assumption. It should be noted, in addition, that during the birth of the earth no geological or organic processes were active which would have been able to modify the primordial isotopic composition of carbon in the upper parts of the

TABLE 1

C^{12}/C^{13} Ratios in Carbonaceous Materials

Sample and Location	C^{12}/C^{13}	Reference*
Carbon from Meteorites		
Homestead, Iowa (*Cgb*)	91.7	M
Estherville, Iowa (*M*)	91.1	M
Finnmarken, Norway (*P*)	91.3	M
Pavlodar, Semipalatinsk, Siberia, U.S.S.R. (*P*)	92.0	M
Cañon Diablo, Ariz. (*Og*)	89.8	M
Cosby's Creek, Tenn. (*Og*)	89.4	NG
Cosby's Creek, Tenn. (*Og*)	91.6	M
Kokomo, Ind. (*Iron*)	91.3	M
Igneous Carbon		
Diamond: Kimberley, Union of South Africa	89.0	NG
Graphite: Ceylon	89.8	NG
Graphite: Ceylon	90.2	M
Calcite (with zeolite): Patterson, N.J.	89.9	M
Calcite: Joplin, Mo.	89.4	M
Calcite from nepheline pegmatite: Bancroft, Ont., Canada	89.8	M
Calcium Carbonate and Limestones		
Clam shell: Boston, Mass. (Recent)	88.7	NG
Marine shell	89.5	M
Limestone: Bermuda	89.0	M
Limestone: Teplitz, Bohemia (upper Cretaceous)	89.3	M
Chalk	89.2	M
Limestone: Bavaria (Jurassic)	89.2	M
Limestone (Mississippian)	89.0	M
Limestone: New Salem, N.Y. (lower Devonian)	89.2	M
Limestone: Champlain Valley, N.Y. (mid-Ordovician)	88.8	M
Limestone: Vermont (Ordovician)	88.6	NG
Limestone: northwestern Vermont (upper Cambrian)	89.4	M
Limestone: Frontenac Co., Canada (pre-Cambrian)	89.3	M
Limestone: Champlain Valley, N.Y. (pre-Cambrian)	89.3	M
Limestone: New York (Grenville)	89.3	M
Limestone: New York (Grenville)	87.9	NG
Graphite from limestone: Parainen, Finland (Archean)	88.4	R
Air and Water		
Air: Massachusetts, 3/14/38	92.5	NG
Air: Massachusetts, 3/22/38	89.9	NG
Air: Minneapolis, Minn., 3/1/41	91.5	M
Carbon dioxide from soil: Tulsa, Okla.	90.5	W
Carbon dioxide from soil: Tulsa, Okla.	90.1	W
Sea water	89.3	M
Bituminous Sediments		
Bottom ooze: Mud Lake, Fla. (Recent)	91.6	M
Oil shale: Elko, Nev. (Miocene or Pliocene)	92.6	M
Kuckersite: Esthonia (Ordovician)	92.7	M
Kuckersite No. 2: Esthonia (Ordovician)	92.5	M
Kolm: Sweden (upper Cambrian)	92.4	M
Shungite: Shunga, K.F.S.S.R. (pre-Cambrian)	92.7	M
Shungite, 1st variety: Shunga, K.F.S.S.R. (pre-Cambrian)	92.9	R
Graphite from carbon-bearing schist: Paakki, Paltamo, Finland (Archean)	90.3	R
Graphite: Kärpälä, Mäntyharju, Finland (Archean)	91.7	R
Graphite from graphite phyllite: Kalkkimaa, Kemi, Finland (Archean)	90.5	R
Carbon from slate fragment: Valkeekivi, Ylöjärvi, Finland (Archean)	91.0	R
Carbon from *Corycium enigmaticum*: Tähtinen, Aitolahti, Finland (Archean)	90.8	R
Carbon from *Corycium enigmaticum*: Tähtinen, Aitolahti, Finland (Archean)	92.0	R
Carbon from *Corycium*-like inclusion: Saarinen, Aitolahti, Finland	91.4	R
Albertite: Nova Scotia, Canada	92.4	M
Green River oil shale: Rulison, Colo.	92.5	M
Kerosene shale: Australia	91.7	M
Alum shale (Alaunerde): Germany	92.2	M
Petroleum and Natural Gas		
Crude oil: Allen, Okla.	92.8	M
Crude oil: Rusk Co., Tex.	92.3	M
Crude oil: Los Angeles, Calif.	92.0	M
Oil: Emba, U.S.S.R.	92.5	M
Oil: Western Texas	91.2	NG
Oil and gas: Barton and Rice Counties, Kan.	94.1	W
Oil: Pottawatomie Co., Okla.	93.2	W
Oil: Winkler Co., Tex.	93.9	W
Oil: Carbon Co., Wyo.	94.1	W
Carbon of Animal Origin		
Clam flesh: Boston, Mass.	90.1	NG
Cod oil	92.1	M
Casein	92.5	M
Gelatin	91.4	M
Carbon of Vegetable Origin		
Linseed oil	92.8	M
Raw China wood oil	92.8	M
Rubber	92.5	M

* References: "NG," Nier and Gulbransen (1939); "M," Murphey (1941); "W," West (1945); "R," Rankama (in press).

TABLE 1—*Continued*

Sample and Location	C^{12}/C^{13}	Reference*
	Carbon of Vegetable Origin	
Spores of *Lycopodium clavatum*	93.1	M
"Balkhashite" algae: Turkestan, U.S.S.R.	92.8	M
Weed: Tulsa, Okla.	92.6	W
Pine wood: Massachusetts	91.5	NG
Pine wood	91.6	M
Oak wood	91.6	M
Maple wood: Massachusetts	91.9	M
Peat: Frostproof, Fla.	92.8	M
Interglacial wood: Kittson Co., Minn.	92.2	M
Wood: Moorhead, Minn. (late Pleistocene)	91.7	M
Wood (Pleistocene)	91.9	M
Spruce wood: Springfield, Minn. (Pleistocene)	91.8	M
Lignite: Siebenberg, Germany (Pliocene-Miocene)	91.8	M
Xyloid lignite: Brandon, Vt. (Eocene)	91.7	M
Underclay of coal: Golden, Colo. (Cretaceous)	91.9	M
Lignite: Pastry, France (Cretaceous)	91.9	M
Bituminous coal: Carillos, N.M. (Cretaceous)	91.5	M
Jet: Whilby, England (Jurassic)	91.3	M
Spore coal: East Liverpool, Ohio (Carboniferous)	92.6	M
Cannel coal: Linton, Ohio (Carboniferous)	92.1	M
Bituminous coal: Coal City, Ill. (Carboniferous)	92.0	M
Bituminous coal: Waukee, Iowa (Carboniferous)	91.6	M
Torbanite, black: Scotland (Carboniferous)	92.0	M
Torbanite, brown: Scotland (Carboniferous)	91.3	M
Semianthracite: Antarctica	92.3	M
Anthracite: Kingston, Pa. (Carboniferous)	91.4	M
Anthracite: Tennessee (Carboniferous)	91.8	NG
Graphitized anthracite: Mansfield, Mass.	91.8	M
Coal ball, organic: Dallas Co., Iowa	91.8	M
Coal ball, inorganic (carbonate): Dallas Co., Iowa	90.6	M

lithosphere. Therefore, it seems to be safe to assume that the original isotopic composition of carbon cannot be that found in the present-day carbons of inorganic or organic origin.

The reaction mechanisms responsible for the fractionation of the carbon isotopes are, as yet, known only incompletely. Isotopic exchange reactions certainly play an important part in the fractionation. Urey and Greiff (1935) have suggested the possibility of at least some separation's taking place by means of the reaction between carbon dioxide and the bicarbonate ion. This exchange reaction is evidently responsible for the concentration of the heavier isotope in carbonate sediments. The separation mechanisms active in connection with igneous phenomena might include diffusion in the gravitational field and in a pressure field, distillation, evaporation, and chemical separations. As to the mechanisms causing the concentration of the light isotope, C^{12}, in animals and plants, it seems to be evident that the organisms form special cases of the fractionation caused by physicochemical systems. Kamen (1946, p. 121) admits that isotope differentiation may be more characteristic of living systems than of inert systems. With special reference to the enrichment of C^{12} in plants, it should be noted that recent investigations of Armstrong and Schubert (1947) indicate that the exchange between carbon dioxide and insoluble carbonates in the leaves is a probable method by which green plants absorb carbon dioxide from the air. These authors have found that a definite exchange of C^{13} occurs between atmospheric CO_2 (containing about 1.1 per cent C^{13} [Belkengren, Nier, and Burr, 1942, Nature, vol. 149, p. 24]) and enriched C^{13} barium carbonate.

The foregoing observations furnish, in addition, some information concerning the cycle of the carbon isotopes between the atmosphere and the sea. This cycle is diagrammatically presented in figure 2, and the reader is referred to the C^{12}/C^{13} values given in table 1. As was pointed out above, C^{13} is enriched in sea water during the exchange reaction between atmospheric carbon dioxide and the bicarbonate ion. During the formation of the carbonate sediments by inorganic or organic precipitation there probably oc-

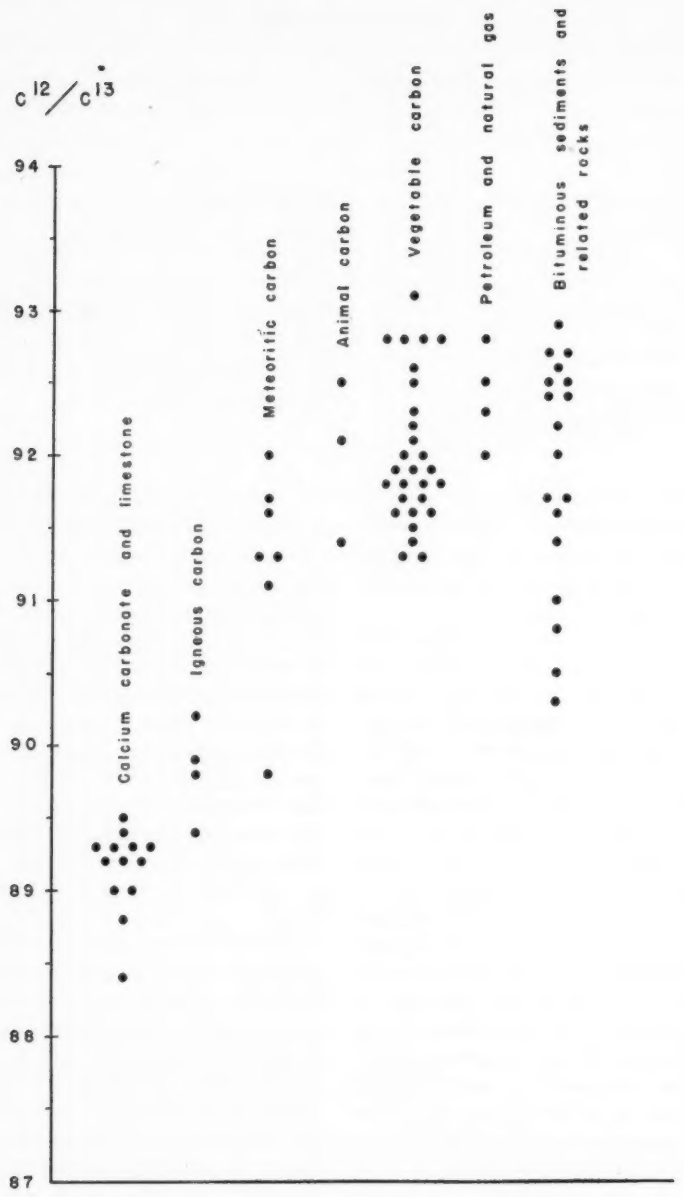


FIG. 1.—C^{12}/C^{13} ratios in carbonaceous materials, classified according to their origin

curs further enrichment of C^{13}, whereas the content of this isotope in the carbonate sediments is bound to decrease when the sediments are brought into contact with the atmospheric carbon dioxide. The light isotope, C^{12}, on the other hand, becomes enriched in marine plants more actively than do any other substances encountered.

Still another fact seems to be of certain interest in this connection. In general, the inorganic processes causing the fractionation of the carbon isotopes seem to be slow as compared with the more rapid

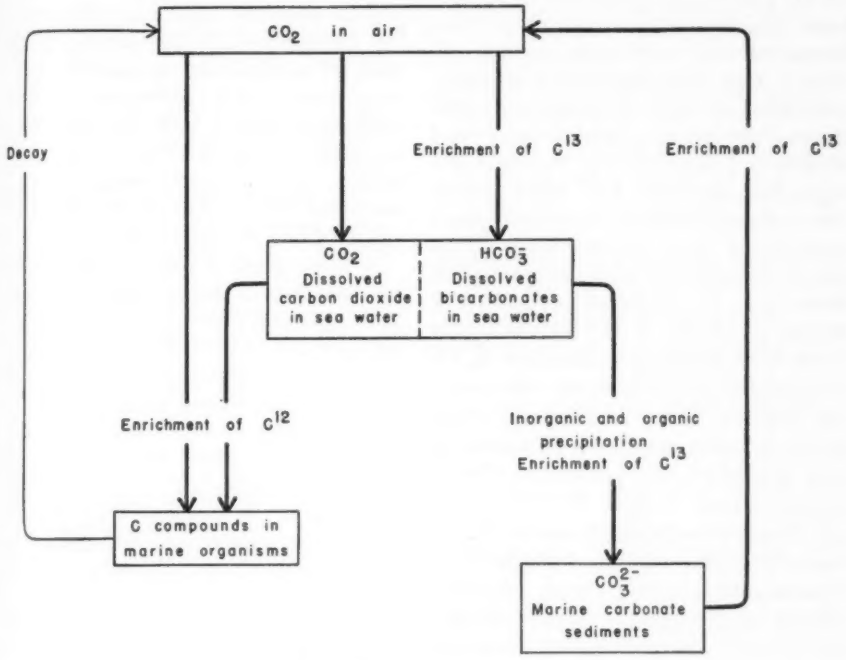


FIG. 2.—Cycle of C^{12} and C^{13} between the atmosphere and the sea

and, consequently, in marine animals feeding upon the plants. During the decay of the organisms a part of the carbon may be carried to the atmosphere as carbon dioxide. As yet, there is no evidence available to show whether or not C^{12} will become further enriched during this process.

As to the animals, the reaction mechanisms seem to be known very inadequately. Belkengren (according to Murphey, 1941) has found that fats reject C^{13} organic processes taking place in nature. In any case, these two processes work continuously in opposite directions; and, to judge by figure 1, the inorganic processes have thus far caused a more thoroughgoing fractionation than have the organic ones. The petroleum hydrocarbons might form a possible exception if the values presented by West are considered, but here the effects of distillation and evaporation may already be effective.

SOME OTHER ABUNDANCE STUDIES OF ISOTOPES BASED ON METEORITES

The oxygen, iron, and copper isotopes have been studied more recently in meteorites, in order to establish the presence of possible variations in their abundance ratios. Manian, Urey, and Bleakney (1934) reported no variations in the isotope ratio O^{16}/O^{18} of stony meteorites as compared with terrestrial oxygen, although they considered that a higher concentration of O^{17} in meteorites might be possible (1934, p. 2608). Valley and Anderson (1941) studied the iron isotopes Fe^{54}, Fe^{57}, and Fe^{58}. Even though the averages published by these authors consistently show slightly lower abundance values of the above isotopes in iron meteorites, as compared with irons of terrestrial origin, it is concluded that there is no significant difference in the composition of the samples. The material used by Valley and Anderson consisted of seven specimens of terrestrial iron ores and twelve meteorites. Unfortunately, these authors did not publish any details concerning the source of their material or the results of the separate determinations. Still more recently, Brown and Inghram (1947) studied the isotopic composition of meteoritic (one sample) and terrestrial copper (two samples). The slight difference found to exist in the Cu^{63}/Cu^{65} ratio is thought to be within the experimental error. However, these authors have based their conclusions on a very limited material, and evidently more determinations are needed to prove the validity of their assumption. By reference to table 1 and figure 1 it may be claimed, by using just one of the meteoritic C^{12}/C^{13} ratios, that the isotopic composition of meteoritic carbon does not materially differ from the composition of the carbon of petroleum or of calcite or that there is a very pronounced difference between meteoritic carbon and the carbon of limestones. However, even in the case of carbon, the seventy-odd samples used to construct figure 1 still cannot furnish all the details of the fractionation.

Another point of view is that, if there are variations in the isotopic composition of Fe, Cu, and other elements, they may be too small to be detected by the present-day mass spectrometric techniques. Here also the general geochemical character of these elements may enter as a deciding factor. Iron is very typically siderophile, although it also possesses chalcophile, lithophile, and biophile trends. Copper is mainly chalcophile, but carbon is geochemically very versatile, being siderophile, clearly lithophile, typically atmophile (as CO_2), and, above all, a decidedly biophile element. In this case the possibility of a pronounced fractionation might be greater than in the case of many other elements geochemically more constant than carbon.

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GEOLOGICAL SIGNIFICANCE OF SURFACE TENSION[1]

JEAN VERHOOGEN
University of California, Berkeley

ABSTRACT

Surface tension is found to be a controlling factor in a number of processes of geological importance: precipitation and solution in small pores and cavities (metasomatism), incipient crystallization, recrystallization and formation of porphyroblasts, vapor tension of a magma, development of pressure by reheating of rocks containing adsorbed water, and possibly surficial aspects of lava flows.

INTRODUCTION

It has not been generally recognized that surface phenomena may play an important part in determining the course of geological processes and the state of equilibrium of geological systems. Bain (1936) apparently was the first to make use of the laws of surface tension and adsorption in the study of metasomatism. Besides this pioneer work and with the exception of a few scattered references, the subject has been usually ignored by geologists and is rarely mentioned in textbooks on geology. The present paper points out a few types of geological processes in which surface phenomena presumably play a part. It is offered in the hope that more attention will be given to this type of phenomenon.

SYMBOLS

The following symbols are used consistently throughout the paper: T is temperature, P pressure, N molar fraction. Lower subscripts refer to a constituent, upper symbols to a phase. Thus N_i^a is the molar fraction of constituent i in phase a, and n_i^a is the number of moles of constituent i in this phase, so that $N_i^a = n_i^a / \sum_i n_i^a$ and $\sum_i N_i^a = 1$. The quantity μ_i is a chemical potential, p_i^* a fugacity, p_i a vapor pressure, and f_i an activity coefficient, the relations between these quantities being

$$p_i^* = p_i f_i = P N_i f_i , \qquad \lim_{P \to 0} f_i = 1 .$$

The symbols V^a and S^a refer, respectively, to the total volume and total entropy of phase a, and v^a and s^a are, respectively, molar volumes and molar entropies. The symbol $\bar{v}_i^a$ is the partial molar volume of i in phase a; a is an area, r a radius of curvature, σ a surface tension, and Γ_i^a the adsorption of i at the interface a. The symbol S^a is the total entropy of the surface phase a, and s^a its entropy per unit area; R is the gas constant per mole (83.15 bar cm^3/1°).

FUNDAMENTAL RELATIONS

The *surface energy* of an interface between two homogeneous phases is a measure of the increase of energy acquired by a molecule which has come from the interior of one of the phases to form a new unit of surface. The *surface tension* σ is usually defined by the relation $dW = \sigma da$, where dW is the work expended on increasing the area of the interface by an amount da. Although these two quantities—surface energy and surface tension—are not identical, they are interchangeable for most practical purposes. The dimensions of σ are energy/area or force/length.

The physical interpretation of surface

[1] Manuscript received December 30, 1947.

tension is, briefly, as follows: Any atom or molecule in a homogeneous phase is in equilibrium under the combined effects of the forces exerted on it by its neighbors. At the surface between phases 1 and 2 an atom is submitted to two different effects, and there is usually a resultant force directed toward the interior of one of the phases, which tends therefore to contract, reducing the area of the interface to a minimum. As the surface tension results essentially from differences in the intermolecular forces on both sides of the boundary, it will depend essentially on the chemical nature of the phases, the nature and magnitude of intermolecular forces, number of atoms within a certain distance of the boundary, i.e., the density of the two phases or, in the case of solid phases, the type of packing and dimensions of the unit cell. Surface tension will, as a rule, be a function of pressure, temperature, and composition of the phases in contact. The surface tension of a substance has no absolute value; we must still define the nature of the phase in contact with it. For crystals the surface tension and surface energy depend on the orientation of the face.

Surface phenomena at the contact of two phases are usually localized in a film of finite thickness. For thermodynamic treatment it is convenient to define an ideal surface of separation, both phases being assumed to remain homogeneous right up to this ideal surface. We assume that surface forces act in this ideal surface only and determine its position in such a manner that the ideal system will be mechanically equivalent to the actual one. It is usually necessary to assign to this ideal surface a certain concentration, called the "adsorption," and defined by

$$\Gamma_i^a = \frac{n_i^a}{a}, \qquad (1)$$

where n_i^a is the number of moles of i in the actual system *minus* the number of moles that would be present if the two phases remained strictly homogeneous right up to the contact (Γ_i^a may thus be positive, negative, or zero). In the same manner it is usually necessary to assign to the ideal surface a certain amount of internal energy E^a and a certain entropy S^a, so that the total internal energy and total entropy will be the same in the ideal and the actual systems. We then have[2]

$$dE^a = T^a dS^a + \sigma\, da + \sum_i \mu_i^a dn_i^a, \qquad (2)$$

which leads to Gibbs's fundamental relation

$$S^a dT^a + a\, d\sigma + \sum_i n_i^a d\mu_i^a = 0. \qquad (3)$$

Dividing by a, we obtain

$$s^a dT^a + d\sigma + \sum_i \Gamma_i^a d\mu_i^a = 0, \qquad (4)$$

and for any change at constant temperature

$$d\sigma = -\sum_i \Gamma_i^a d\mu_i^a. \qquad (5)$$

Equation (4) is quite similar to the usual relation for volume phases,

$$-s^a dT + v^a dP - \sum_i N_i^a d\mu_i^a = 0. \qquad (6)$$

The conditions for equilibrium in a system of c-constituents and φ-phases $\alpha, \beta, \ldots, \varphi$ separated by $\varphi - 1$ interfaces $(\alpha\beta) \ldots$ are

$$\mu_i^\alpha = \mu_i^\beta = \ldots = \mu_i^{\alpha\beta} = \ldots \quad (i = 1, \ldots, c), \qquad (7)$$

$$T^\alpha = T^\beta = \ldots = T^{\alpha\beta} = \ldots, \qquad (8)$$

$$\left.\begin{aligned} P^\alpha - P^\beta &= \left(\frac{1}{\rho_1} + \frac{1}{\rho_2}\right)^{\alpha\beta} \sigma^{\alpha\beta}, \\ P^\alpha - P^\gamma &= \ldots, \end{aligned}\right\} \qquad (9)$$

[2] For proof of the following formulas the reader is referred to one of the standard texts on the subject, e.g., Guggenheim (1934) or Defay (1934).

ρ_1 and ρ_2 being the principal radii of curvature of surface $(\alpha\beta)$; they are considered positive if the corresponding centers of curvature are on the α-side of the surface. Putting $1/r^{\alpha\beta} = \frac{1}{2}(1/\rho_1 + 1/\rho_2)^{\alpha\beta}$, we have

$$P^\alpha - P^\beta = \frac{2\sigma^{\alpha\beta}}{r^{\alpha\beta}}, \qquad (10)$$

which may be written in the differential form,

$$dP = 2d\left(\frac{\sigma}{r}\right). \qquad (11)$$

Relation (10) is of fundamental importance. It may be put under a number of classical forms, such as the Kelvin equation, $\log p_1/p_0 = 2\sigma v/rRT$, relating the vapor pressure of a pure liquid to the radius of the drops; or the Thomson equation, $(T_0 - T_r)/T_0 = (2\sigma/r)(M/Qd)$, relating the melting-point of a grain of radius r to that of a grain with plane surfaces.

For a system of c-constituents and φ-phases separated by $(\varphi - 1)$ interfaces, b of which are plane and $(\varphi - 1 - b)$ are curved, the variance w is

$$w = c + 1 - b, \qquad (12)$$

which reduces to the usual form $w = c + 2 - \varphi$ for $b = \varphi - 1$ and to

$$w = c + 1 \qquad (13)$$

for $b = 0$.

We now proceed to indicate a few geological processes in which surface phenomena may play an important part.

SOLUBILITY-METASOMATISM

Consider a pure solid i, and let σ be the surface tension at the curved interface between the pure amorphous solid and its saturated solution in any solvent. According to equation (13), the variance of the system is 3, and the state of the system will be defined by three arbitrary variables, for instances, P, T, and r, r being the curvature of the interface. Then, at P, T constants

$$\frac{dN_i}{dr} = \frac{-2\,\frac{\sigma \bar{v}_i}{r^2}}{\left(\frac{\partial \mu_i}{\partial N_i}\right)_{P,\ T,\ r}}; \qquad (14)$$

and since $(\partial\mu_i/\partial N_i)_{P,\ T,\ r} > 0$ in any stable phase, $dN_i/dr < 0$ if $\bar{v}_i > 0$. Thus the solubility increases when the grain size decreases, and small fragments are more soluble than larger ones. If small and large grains are simultaneously in contact with a given saturated solution, the smaller grains will dissolve, while precipitation occurs around the larger ones, the general tendency being toward the formation of a few large grains and the reduction of the total area of the interface solid/liquid.

For an ideal solution

$$\left(\frac{\partial \mu_i}{\partial N_i}\right)_{P,\ T,\ r} = \frac{RT}{N_i}; \qquad (15)$$

and, assuming σ and $\bar{v}_i$ to be constant in the range considered, we obtain by integration

$$\frac{N_i^2}{N_i^1} = \exp \frac{2\sigma \bar{v}_i}{RT}\left(\frac{1}{r_2} - \frac{1}{r_1}\right), \qquad (16)$$

where N_i^1 and N_i^2 are, respectively, the molar fractions of i in a solution saturated with respect to grains of radius r_1 and r_2. Take, for instance, $\sigma = 10^3$ cgs, $\bar{v}_i = 100$ cm.^{3}, $T = 300^\circ K$, $r_1 = 10^{-5}$ cm., $r_2 = 10^{-3}$ cm.; then

$$N_i^1 = 2.22 N_i^2.$$

If the solid is in contact with a solution contained in pores of the solid itself, then the sign of the curvature r is reversed, and so are the signs in equation (14). It follows that if $\bar{v}_i > 0$ the solubility will decrease in smaller openings, which will

tend to close, the larger openings becoming larger, and the general tendency being, as usual, to decrease the total area of contact.

Thus when a saturated solution of a number of constituents is introduced at constant temperature into a small pore, it will become oversaturated with respect to all constituents for which $\bar{v}_i > 0$ and undersaturated with respect to those for which $\bar{v}_i < 0$. The solution will thus generally precipitate some of its constituents and will be able, at the same time, to dissolve further amounts of some others. It follows that the behavior of a solution impregnating a rock will depend on the size of the pores and that minerals which might precipitate in a large opening may go into solution in a smaller one, or vice versa. This is a common observation (Lindgren, 1933, p. 173), for which the writer has been unable to find a correct explanation in the literature.[3]

The effect of a given solution impregnating a given rock will depend on the following factors: the magnitude of the surface tension of the solution against the various minerals in the rock; the shape and size of the cavities and pores; the shapes and sizes of individual grains in contact with the solution; and the partial molar volume of the various constituents of the solution, to which factors we must add, of course, all those which are usually considered in this connection, viz., pressure, temperature, permeability, etc.

Thus the behavior of a given solution with respect to metasomatic replacement may be expected to be extremely diversified. It is practically a hopeless task to predict, in the case of a multicomponent solution impregnating rocks of different composition and porosity, which substances will precipitate and where and when and which substances will be carried away.

CRYSTALLIZATION

Because a small grain is more soluble than a large one, it follows that, when precipitation or crystallization begins, i.e., when the dimensions of the incipient grains are extremely small, there must be a certain amount of supersaturation with respect to a larger mass of the solid phase. This is why crystallization starts more readily when "germs" of finite size are present. It has been shown statistically (Landau and Lifshitz, 1938) that the probability of formation of a germ of given radius is a function of $e^{-\sigma}$ and thus decreases rapidly when the surface-tension grain/solution increases; in some cases, germs may have to be added from outside.

The problem becomes more complicated in the case of crystals, because σ will then be different in different directions. Gibbs (1928, p. 320) has shown that the condition for stability, for a given volume v of the crystal, is that $\sum_i a_i\sigma_i$ be a minimum, where a_i is the area of a face with surface energy σ_i, the summation being extended to all faces of the crystal. Gibbs's equation (666) states more explicitly that the quantity

$$\frac{\Sigma\,(\sigma_i l_i \operatorname{cosec} \omega_i - \sigma_i l_i \cot \omega_i)}{a_i} \qquad (17)$$

[3] Bain (1936) explains such facts by the variation of pressure which, according to Bernoulli's theorem, must result from variations in the velocity of the solution. Now this pressure variation is $\delta P = \frac{1}{2}\rho(\delta v)^2$ where ρ is the density of the solution and δv is the change in the velocity. Since the velocity of the solution probably never exceeds a few centimeters per second, δv is less than this, and, accordingly, the change in chemical potential of constituent i $\delta\mu_i = \bar{v}_i\delta P$ is only of the order of 10^2 ergs for $\bar{v}_i = 100$ cm^3. From equation (11), on the contrary, we find for $\sigma = 10^2$ cgs, $r = 10^{-5}$ cm., variations of μ_i which are of the order of 10^8 ergs. The effects of changes in velocity are thus quite negligible compared to surface-tension effects.

must be the same for all faces, a_i being the area of the face on which the crystal grows, l_i the length of the common edge between this face and an adjacent face of area a_i' and surface energy σ_i', the summation being extended to all faces adjacent to face i. The quantity ω_i is the external angle between the two faces. The expression (17) measures the differences in chemical potential between face i and the same amorphous solid. As Gibbs points out, the value of the chemical potential in the solution which will be necessary for the growth of the crystal face will usually be different from that required for precipitation of the same solid in the amorphous state and will generally be greatest for the faces for which σ is least.

It has been shown (Volmer, 1939) that if, for example, we start from a prismatic crystal having faces 1, 2, . . . , and measure the growth normal to each face by the lengths h_1, h_2, . . . , we must have, at equilibrium,

$$\frac{\sigma_1}{h_1} = \frac{\sigma_2}{h_2} = \ldots, \qquad (18)$$

a relation known as "Wulff's law." The growth of an incipient crystal is therefore essentially determined by the surface energy of its various faces.

RECRYSTALLIZATION

As has been pointed out, there will always be a tendency for any system under given conditions to reduce the area of the interfaces to a minimum. This tendency corresponds to the tendency for a rock to become equigranular, smaller crystals going into solution at points of maximum curvature and precipitation occurring on larger grains at points of less curvature. The presence of a solvent is, of course, not necessary; transport of material might occur by diffusion; but, as diffusion is an extremely slow process at ordinary temperatures, the presence of a solvent will notably accelerate the process. This type of recrystallization is quite independent of any exterior action such as heat, pressure, or stress, and it may occur before, during, or after any mechanical deformation to which the rock may be submitted. In the same manner, disseminated amounts of a given mineral will tend to concentrate in larger units (porphyroblasts). This tendency to form porphyroblasts will depend essentially on the magnitude of the surface energy which, as we have mentioned, is a function essentially of the magnitude of intermolecular forces, type, and closeness of packing. Surface energy may thus be an important factor in metamorphic processes.

VAPOR PRESSURE

The composition of a gas phase in equilibrium with a magma will depend, because of equation (10), on the size of the bubbles. Two bubbles of the same composition but of different size cannot simultaneously be in equilibrium. Bubbles of different sizes must necessarily have different compositions.

In the same manner, the composition of the gas phase permeating the pores of the wall rock will be different from that of a gas phase in equilibrium with the magma through a plane interface.

Conversely, the composition of the gases held in solution in, or adsorbed on, a crystal is not necessarily the same as that of the gas phase that was being given off by the magma at the time of crystallization. Shepherd (1938) has already called attention to the fact that adsorption may complicate in a hopeless manner the determination of the exact composition of a magmatic gas phase.

It is interesting that the vapor pres-

sure of a magma may be determined from adsorption and surface-tension data. Consider, for instance, a simple system consisting of a pure gas (phase 1, constituent 1), a solution (phase 2, constituents 1 and 2), and a pure solid (phase 3, constituent 2). Such a system would be normally univariant. If the interfaces are curved, the variance is 3. The equations are (*a*) three equations of type (6), one for each phase; (*b*) two equations of type (10); and (*c*) two equations of type (4). These may be written as follows:

$$\left.\begin{aligned}
&-v^1dP^1+s^1dT+d\mu_1=0\,,\\
&-v^2dP^2+s^2dT+N_1d\mu_1+N_2d\mu_2=0\,,\\
&-v^3dP^3+s^3dT+d\mu_2=0\,,\\
&dP^1-dP^2=\frac{2}{r^{12}}\,d\sigma^{12}\,,\\
&dP^2-dP^3=\frac{2}{r^{23}}\,d\sigma^{23}\,,\\
&-s^{12}dT-d\sigma^{12}-\Gamma_1^{12}d\mu_1-\Gamma_2^{12}d\mu_2=0\,,\\
&-s^{23}dT-d\sigma^{23}-\Gamma_1^{23}d\mu_1-\Gamma_2^{23}d\mu_2=0\,.
\end{aligned}\right\} \tag{19}$$

First, suppose that all the adsorptions are negligible. Eliminating $d\sigma^{12}$, $d\sigma^{23}$, dP^2, dP^3, $d\mu_1$, and $d\mu_2$, we find for the variation with temperature of the vapor pressure P^1

$$\frac{dP^1}{dT}=\frac{N_1\Delta s_1-N_2\Delta s_2-N_2v^3\left(2\,\frac{s^{23}}{r^{23}}+2\,\frac{s^{12}}{r^{12}}\right)+v^2\,\frac{2\,s^{12}}{r^{12}}}{N_1\Delta v_1-N_2\Delta v_2}\,, \tag{20}$$

where

$$\Delta v_1=v^1-\bar{v}_1^2\,,\qquad \Delta S_1=s^1-\bar{s}_1^2\,,$$
$$\Delta v_2=\bar{v}_2^2-v^3\,,\qquad \Delta S_2=\bar{s}_2^2-s^3\,.$$

For $r^{12}=r^{23}=\infty$, this equation reduces to the familiar relation for the vapor pressure of a univariant system of two constituents (Goranson, 1938, p. 84).

Now take $r^{23}=\infty$, $\Gamma_1^{23}=\Gamma_2^{23}=\Gamma_2^{12}=0$, $\Gamma_1^{12}\neq 0$. We then have

$$\frac{dP^1}{dT}=\frac{N_1\Delta s_1-N_2\Delta s_2+\frac{2}{r^{12}}\,(s^{12}-\Gamma_1^{12}s^1)\,(N_1\bar{v}_1^2+N_2\Delta v_2)}{N_1\Delta v_1-N_2\Delta v_2-\frac{2\,v^1}{r^{12}}\,\Gamma^{12}\,(N_1\bar{v}_1^2+N_2\Delta v_2)}\,. \tag{21}$$

The quantity s^1 is usually much greater than Δs_1, and $\bar{v}_1^2$ for water vapor is of the order of several tens of cubic centimeters in the temperature-pressure range considered, so that $(2/r^{12})\Gamma_1^{12}s^1N_1\bar{v}_1^2$ may be of the same order of magnitude as $N_1\Delta s_1$ if Γ_1^{12}/r^{12} is 10^{-2} or greater. The same applies to the last term in the denominator, which may become of the same order as the first time. Adsorption may, therefore, introduce an appreciable correction in the vapor-pressure curve.

Finally, if $r^{12} = r^{23} = \infty$ but Γ_1^{12} and $\Gamma_2^{22} \neq 0$, the equations are, omitting unnecessary indices,

$$\left.\begin{aligned} &-v^1 dP + s^1 dT + d\mu_1 = 0 \,, \\ &-v^2 dP + s^2 dT + N_1 d\mu_1 + N_2 d\mu_2 = 0 \,, \\ &-v^3 dP + s^3 dT + d\mu_2 = 0 \,, \\ &-s^{12} dT - d\sigma - \Gamma_1 d\mu_1 - \Gamma_2 d\mu_2 = 0 \,. \end{aligned}\right\} \quad (22)$$

The first three equations yield the usual relation

$$\frac{dP}{dT} = \frac{N_1 \Delta s_1 - N_2 \Delta s_2}{N_1 \Delta v_1 - N_2 \Delta v_2}, \quad (23)$$

whereas, by eliminating $d\mu_1$ and $d\mu_2$, we obtain

$$\frac{dP}{dT} = \frac{\Gamma_1 s^1 + \Gamma_2 s^2 - s^{12} + \dfrac{d\sigma}{dT}}{\Gamma_1 v^1 + \Gamma_2 v^2}. \quad (24)$$

Equations (23) and (24) are thus equivalent, and either may be used. Equation (23) is, of course, the easier one to use, as quantities such as adsorptions and surface entropies are difficult to measure. However, the vapor pressure of this simple system *could* be calculated from surface-tension data alone.

ADSORPTION

Let us consider a rock containing a certain amount of water adsorbed on its surface and compute roughly the pressure under which this water would be liberated if the adsorption forces ceased suddenly to exist. Let A be the surface per unit mass of the rock (A, for some substances, may be of the order of 10^7 cm²/gr). Suppose that all the pores are of radius r. Then the number of pores, n, is

$$n = \frac{A}{4\pi r^2},$$

and their total volume is $\frac{1}{3}Ar$. If n^a is the number of moles of a perfect gas adsorbed in the pores, the pressure that would develop in the pores if the adsorption forces suddenly ceased to exist would be

$$P^a = n^a \frac{3RT}{A\,r}.$$

Hence

$$n^a = P^a \frac{A\,r}{3RT}.$$

The number of moles n^β that would be present in the pores at the outside pressure P^β is

$$n^\beta = P^\beta \frac{A\,r}{3RT};$$

and the adsorption Γ is therefore

$$\Gamma = \frac{n^a - n^\beta}{A} = \frac{r}{3RT}(P^a - P^\beta); \quad (25)$$

and, finally,

$$P^a = \frac{3RT\Gamma}{r} + P^\beta. \quad (26)$$

Consider a rock with pores of radius 10^{-5} cm., surface 10^3cm²/gr, and containing 0.18 per cent of adsorbed water, so that $n^a = 10^{-4}$ moles/gr. The adsorption Γ is then $10^{-4}/10^3 = 10^{-7}$, and, at 1,000° C.,

$$P^a = 3{,}240 + P^\beta \quad \text{(bars)}.$$

Adsorption is known to decrease rapidly when temperature increases. It follows that if a rock containing as little as 0.18 per cent of adsorbed water could be heated up rapidly to 1,000°—a temperature at which we assume that desorption is complete—the water vapor would be released under very high pressure. The figure obtained is, of course, only approximate, because at this pressure the gas ceases to be perfect and, moreover, the postulate of spherical porosity is probably not satisfied. Nonetheless, very high pressures may originate in this manner, and desorption resulting

from rapid heating may be a factor in some types of explosive volcanic activity.

It is believed also, although the matter has not been thoroughly investigated, that surface tension may control to some extent the surficial aspects of lava flows. Surface tension, as is well known, controls the spreading of a liquid on a solid surface and also the size and shape of drops formed when a thin vein of viscous liquid flows through a small opening. The size of the bubbles which may form in a lava flow and the growth of crystals in this lava are, as we have seen, also controlled to some extent by surface tension. These factors are probably of some importance in determining the surficial aspects of lava flows.

It must be emphasized, however, that surface-tension effects such as we have considered depend essentially on the curvature of the interfaces and become vanishingly small if the curvatures become small.

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HOLLOW FERRUGINOUS CONCRETIONS IN SOUTH CAROLINA[1]

LAURENCE L. SMITH
University of South Carolina

ABSTRACT

Ferruginous concretions are locally abundant in sands and sandy clays of the South Carolina Coastal Plain. The great variety of shapes is primarily determined by the structure of the enclosing sediments. Hollow forms result from intergranular deposition of limonite in excess of that necessary to fill interstices between sand grains. The outer zone of solid concretions receives greater increments of iron oxides and, being thus forced to expand more rapidly, results in hollow interiors. The rate of supply of material is an important factor in determining the form of the concretions.

INTRODUCTION

Concretions similar to those in South Carolina have been described from other localities and are apparently of widespread occurrence, particularly in warm, humid climates. Wherever concretions are abundant, gradation from solid to hollow types is usually found. This gradation suggests that the hollow ones form by the same processes that are responsible for the solid types.

No evidence has been found of hollow interiors formed by solution of carbonate cores. In some, limonite was deposited around clay balls, which, by dehydration, formed interior cavities. But the function of the clay interior has been primarily that of a nucleus around which precipitation of the limonite was localized. In general, the hollow concretions were formed by continued deposition of limonite cement in sufficient amounts to wedge apart the sand grains.

OCCURRENCE AND ASSOCIATIONS

Ferruginous concretions in South Carolina occur in sediments which vary from coarse sands to sandy kaolins and range in age from Cretaceous to possibly Pleistocene. They are locally abundant where ferruginous sands overlie more impervious materials, as in the Fall Line belt, where a blanket of red to buff sands rests upon clayey members of the Tuscaloosa or upon the crystalline rocks. Ferruginous fossil wood has been found in abundance at several localities in South Carolina under the latter stratigraphic conditions. The water table is also a favorable zone of limonite deposition.

The blanket of post-Cretaceous sands has a maximum thickness of about 50 feet. These sands are cross-bedded and show considerable variation in texture and color. Some consist almost entirely of quartz grains with varying amounts of limonitic cement. Some mica and opaque minerals may be present.

Mottling is generally pronounced. Above the water table this feature is due to leaching of iron, and the spots are gray or buff against a red background. Below the water table the mottling is due to deposition of limonite, the spots being various shades of red and brown, developed in lighter-colored sands. Numerous chemical analyses have shown that the red spots contain from three to seven times as much iron oxide (calculated as Fe_2O_3) as do the enclosing sands. The red spots generally range from 0.4 to 3 per cent iron oxide and the normal sands from 0.1 to 0.6 per cent. Thus the red

[1] Manuscript received May 20, 1947.

mottling is not due simply to oxidation of iron but to actual concentration of iron oxide.

The sands beneath surface depressions, in which organic remains have accumulated, are uniformly bleached and leached of iron, which is carried to lower levels. Sections exposing the former position of the water table reveal stratiform ferruginous deposits at this level and also just above relatively impervious layers. The writer has found similar conditions in drilling undrained depressions. From this, together with the widespread mottling, it is obvious that in warm, humid climates iron is readily leached, transported, and redeposited in sediments. Gradation from limonite-rich spots to solid and hollow concretions has been found, and all result from the same general processes.

COMPOSITION AND FORM OF THE CONCRETIONS

The concretions are composed of the same materials as the enclosing sediments, differing only in the greater percentage of iron oxide cement.

Stratiform concretionary deposits are the most common type. Thin layers, commonly interbedded with the sands, are localized just above relatively impervious bases. Most kaolin beds are capped by iron-cemented layers, in places several feet thick and of sufficient firmness to serve as dimension stone. Scattered concretions of all shapes may occur just above the stratiform deposits or may be intergrown with them in such a manner as to indicate that the smaller concretions developed first and were later incorporated in the limonite-cemented layer.

Isolated concretions are variously spheroidal, ellipsoidal, lens-shaped, fusiform, rod-shaped, cylindrical, or nodular. They range in size from a fraction to several inches in thickness, and tubular forms 3 feet long have been found. Smaller concretions are most likely to be spheroidal; larger concretions are less regular. One shape or related shapes characterize a given zone.

Scattered concretions exhibit great variation in size of interior cavities, which bear no relation to the size of the whole concretion. Large concretions may have incipient or small cavities surrounded by thick walls, whereas many small ones may have thin shells, with cavities amounting to 75 per cent of the volume of the whole. The shapes of the cavities conform closely to the outer form, elongated concretions having tubular openings and flat forms containing voids of comparable outlines. The shells are generally quite uniform in thickness, particularly in the spheroidal forms. Unsymmetrical types, with one side more highly arched, show the more convex wall to be thicker.

The interiors are partially filled with ferruginous sand, which in most cases differs from the enclosing shell only in compactness and amount of limonite cement. Only in concretions formed around clay balls is there any difference between the shell and the core material. Some cores are compact and show only slight separation from the walls; others consist of vuggy, weakly cemented sands; and many have hollows partially filled with loose sand, which rattles when the concretion is shaken.

Chemical analyses show that iron oxide constitutes a larger proportion of the shell material than of the loose interiors. Examinations of thin sections showed that the percentage of ferruginous cement is greatest at approximately the middle of the shells.

Concentric fractures develop in con-

cretions with incipient hollows (pl. 1). The fractures conform to the surface of the concretions and are more or less parallel to one another. Drusy limonite coatings indicate that the cracks formed before completion of limonite deposition.

Microscropic examination of thin sections shows the sand grains widely separated by intergranular limonite cement (fig. 1). The mica flakes are bent and the quartz shattered by forces attendant upon deposition, the amount of disruption increasing with increase in amount of limonite.

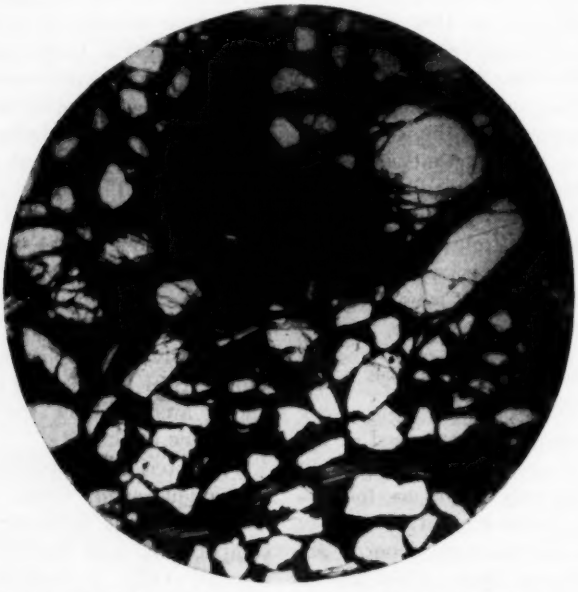


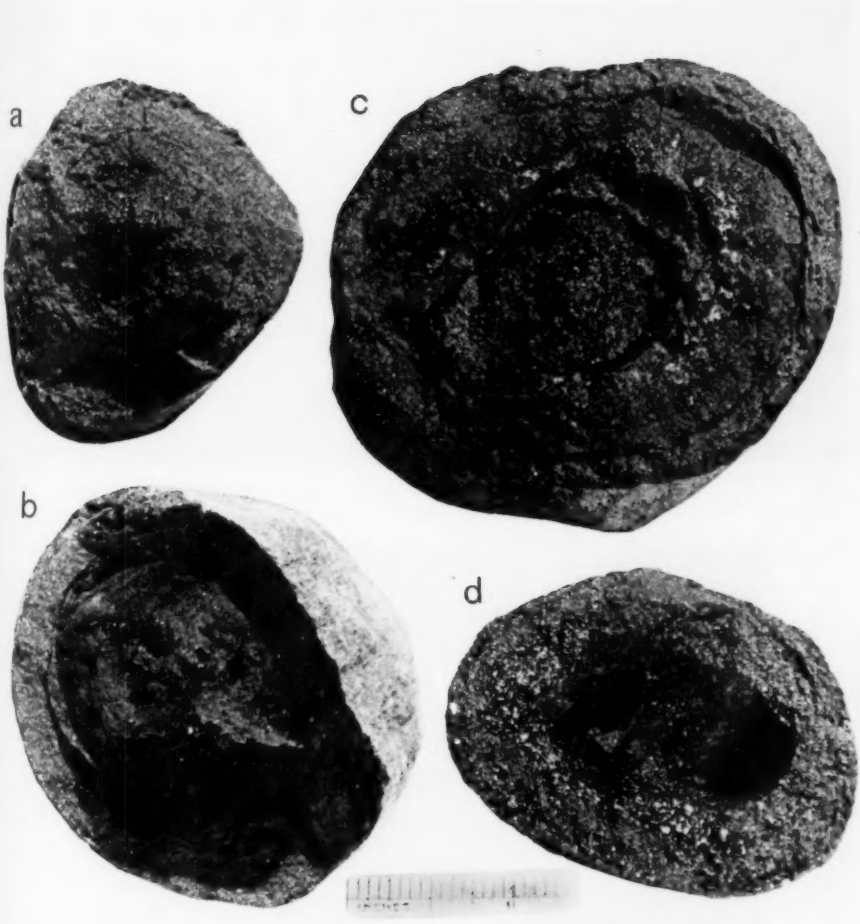
FIG. 1.—Photomicrograph showing section of shell of hollow ferruginous concretion. All of black area is limonite. Intergranular deposition of limonite has bent the mica and shattered quartz grains. ×35.

ORIGIN OF HOLLOW FERRUGINOUS CONCRETIONS

Iron, leached from ferruginous sands by meteoric waters, is probably transported in the form of ferric oxide hydrosol. The more thorough leaching beneath depressions containing organic matter indicates that solution is facilitated by organic acids. Deposition at depth begins around some local precipitating agent, and cementation of the sands takes place by interstitial secretion of limonite. Deposition proceeds outward from the initial locus, and, because the building material is received from the surrounding area, the periphery of the concretion grows most rapidly in directions of greatest supply, which accordingly determines the shape.

After interstitial spaces are filled, additional deposition of limonite forcefully wedges the sand grains apart. The crustal area expands, whereas the core receives little or no secretion after completion of interstitial filling, with the result that the growing concretion develops a hollow interior.

PLATE I



Ferruginous concretions from near Patrick, S.C., showing stages in development from solid into hollow forms. Note concentric tension fractures in *a* and *b*, separation of core in *b* and *c*, and loose sand and iron oxide in interior of *d*.

PLATE II

A

B

a, Ellipsoidal hollow ferruginous concretion. The interior is partially filled with weakly cemented sand. *b*, Bicameral tubular ferruginous concretion. Note greater thickness of outside wall of small chamber.

Todd (1903, pp. 353–368), noting calcareous concretions with cracks radiating from the center, postulated that the outer portion had

> expanded and become too large for the interior, and has done so with sufficient force to wrench apart the interior. Solidification takes place . . . largely between the particles already deposited, wedging them apart with force sufficient to separate the portion inside the expanding zone.

He called such growths "intercretions" and, to the writer's knowledge, is alone in offering such an explanation for any type of concretion. However, hollow limonitic concretions which do not show comparable radiating cracks were explained by Todd (1903) as due to deposition of iron oxide around a ferrous carbonate "intercretion," with subsequent solution of the included core.

Bates (1938), in discussing hollow limonite concretions occurring in certain tills of Iowa, thinks that Todd's explanation seems applicable. He says:

> The history of hollow concretions may be summarized as follows: (1) the formation in glacial till of siderite concretions most of which were not pure siderite but included some of the surrounding material . . . (2) solution of the iron carbonate and precipitation of ferric hydroxide as a crust around the siderite.

Shaw (1917) offers a similar leaching process to explain hollow pebbles of iron oxide occuring in the bluff of the Mississippi River at Natchez. He states that iron compounds seem partly to have replaced the lime carbonate of limestone pebbles and that each concretion contains a little clay that is indistinguishable from the residue of limestone after the lime carbonate has been dissolved with acid. Shaw shows excellent photographs of a variety of ferruginous concretions; all his forms may be duplicated from localities in South Carolina. Concretions from Shaw's[2] locality, which the writer examined, were apparently formed by deposition around clay balls. Subsequent growth by expansion of the limonite shell, together with possible shrinkage of the clay core, left a void between crust and interior kernel. A similar explanation is believed to apply to the hollow limonite concretions described by Bates.

Tarr (1935), in his excellent treatise on concretions in the Connecticut Valley, believes that the cementing material does not exceed the available pore space. Concerning the calcareous concretions, which are far more numerous in that locality than are the ferruginous ones, he regards the 35–53 per cent of $CaCO_3$ cement as significant, since this amount fits rather closely to the maximum porosity of the enclosing silt. He says:

> The introduction of more than 50 per cent of $CaCO_3$ would have resulted either in a disturbance of the beds about the concretions or in replacement . . . concretions formed in disturbed beds preserve in perfect detail the folds and faults of the enclosing layers. The concretions are simply cemented portions of the enclosing layers.

It is to be noted that these concretions are very impure, the calcareous types containing considerable magnesium carbonate, iron, and aluminum oxides. These impurities suggest rapid deposition, as Tarr concluded from other evidence, and growth would proceed by enmeshing addition silt, with no tendency for intergranular secretion beyond that necessary to fill the voids. The writer has invariably found relatively large cavities within ferruginous concretions formed in kaolins. Here growth has been particularly slow and constant, with opportunity for the diffusion of molecules to the supersaturated adsorbed films in contact

[2] Specimens furnished Stephen Taber through courtesy of Dr. Shaw.

with interstitial limonite. Thus deposition tends to continue adding to that already present, and intergranular secretion would dominate, whereas rapid deposition would create new centers of precipitation and enmeshing of additional particles would result.

Although Tarr (1935) finds sedimentary structures preserved and no evidence of concretions making room for themselves, others (Daly, 1900, and Taber, 1919) have offered graphic evidence of arching of bedding planes by growth of calcareous concretions.

In hollow concretions examined by the writer, iron oxide (calculated as Fe_2O_3) constitutes over 60 per cent of the shells, whereas the loose core material contains less than 50 per cent. The intergranular limonite tends to obliterate all primary sedimentary structures, which are, therefore, indistinguishable inside the oxide shell. In solid forms bedding may be traced through the concretion.

Growth during the early stages of solid ferruginous concretions proceeds rapidly and largely by enmeshing of particles. Thus arching of enclosing materials does not take place. The concretions of other writers, which show displacement of beds, have grown slowly with consequent exclusion of surrounding particles. Evidence that expansion of hollow types arches the enclosing materials has not been found in South Carolina and would not be expected because of the loose character of the sediments. However, the exertion of effective forces by intergranular deposition is convincingly shown by the shattered quartz grains and bent mica flakes (fig. 1), as well as by the concentric fractures, which intersect cement and included grains alike. The disruption of minerals increases with greater amounts of limonite and is absent where cementing material is only sufficient to fill the interstices. Drusy limonite coatings on the fracture surfaces show that breaking took place during the process of secretion.

LOCI AND MODE OF DEPOSITION

Initial precipitation is most commonly localized by some type of void, such as spots of coarser sand, minute cavities, and, to some extent, root holes and fractures. Deposition also begins around clay balls, fossil wood, and possibly pre-existing particles of iron oxide.

Sands which have become mottled by leaching are depleted of iron from existing voids, such as coarser-textured spots and fractures. Below the water table, where mottling is due to deposition, the voids serve as locales of concentration. Limonite is first precipitated upon the surfaces of coarser particles,—filling of interstices follows, and, finally, the mass is cemented into a concretion. Alternate wetting and drying may explain initial precipitation in some voids above the water table, but within the zone of saturation the principal factor is believed to be the greater mobility of dispersed sol molecules where voids are larger. Supersaturation is first attained in the layers of liquid held to the walls of particles by adsorption and would be attained simultaneously throughout the whole system. However, the greater volume of solution in the larger voids permits more effective diffusion of molecules, and so centers of deposition are selectively developed within existing cavities. Once precipitation is begun, equilibrium is maintained by diffusion of colloidal particles from the surrounding zone, and deposition continues by molecular attraction as long as limonite and saturated solution are in contact.

Small spherical cavities, probably due to solution and common in kaolinitic

clays, are conspicuous points of initial precipitation. Their surfaces are first coated with limonite, which either thickens into an incrustation or forms a mesh-like aggregate within the opening. Later secretion extends outward very slowly, resulting in maximum intergranular deposition, as explained above, and thus shells are readily expanded, with interior cavities soon becoming relatively large. Spherical tension cracks dividing the walls into concentric layers attest to the efficacy of the expansion of the outer shells.

Shrinkage cracks and root holes may be incrusted with limonite, but neither are important in localizing deposition, probably because they are not common below the water table. There is no evidence that thick-walled tubular concretions have grown inside root cavities.

Many concretions develop around clay balls or clods of sand weakly held together by clay. These are grouped along definite planes, where the balls were probably formed by waves. The balls, being less pervious to large diffusing molecules of ferric hydroxide, selectively filter them out around their periphery. After definite crusts are formed, continued intergranular secretion results in expansion, and the included ball becomes loose and only partially fills the interior. The hollow concretions described by Shaw (1917) have this origin, and several of his specimens examined by the writer contain a loose kernel of hardened homogenous clay. Concretions that have formed around a ball of partially cemented sand now contain a loose mass of rattling particles left by the drying of the adhering clay.

Fragments of fossil wood were found inside two medium-sized spheroidal concretions. They were attached to one side of the inner wall, and the cavity was partly filled with a residue of sand and limonite particles. The wood apparently served to localize deposition in the same manner as did the clay balls.

FEATURES CONTROLLING GROWTH AND SHAPES OF CONCRETIONS

The various shapes of concretions and ferruginous aggregates have been determined by the structures of the enclosing sediments.

Stratiform concretionary deposits occur above relatively impermeable layers. Probably such limonitic beds are formed just as readily above as below the water table, provided that there is a sufficient overburden of ferruginous material from which iron may be leached.

Spheroidal types occur in relatively structureless materials ranging from coarse sands to kaolins. In such sediments iron molecules are transferred toward the growing aggregates with equal ease in all directions, and additions are deposited symmetrically.

Compound spheroidal or nodular concretions are generally found in association with simple spheroidal types. Some are the result of attachment of additional units to earlier-formed aggregates, and the nodules simply have one wall in common. Others are composed of hollow nodules, the chambers of which are mutually confluent, indicating that the individuals merged early in the process of accretion and that all developed cavities concurrently with their later growth.

Spheroidal concretions and stratiform deposits represent the extremes between which there is a wide range of variations. Rounded types predominate in homogenous sediments and flat ones in materials with marked stratification. In a kaolin pit near Edmund, South Carolina, an abundance of spheroidal concretions occurs in the upper part of massive-

appearing clay. There are also some pod- and lens-shaped types which have their longer axes horizontal and obviously concordant with obscure bedding. The contact of the kaolin with an overburden of sands is marked by limonite-cemented sheets. Associated with these is an assortment of flat concretions but no spheroidal types.

A highway cut, 8 miles south of Lugoff, South Carolina, exposes ferruginous sands with pronounced horizontal structure. Limonite layers 1 inch in thickness parallel the bedding and spread out horizontally for several feet. Along the same horizons are numerous detached concretions which have flat shapes simulating lenses, ellipsoids, or pods (pl. 2, *A*). Many of them are scarcely 1 inch thick while measuring 1 foot horizontally, yet all that were examined contained cavities. Apparently, the stratiform aggregates were supplied almost entirely from above, while detached flat concretions probably received additions from below and laterally as well as by downward diffusion.

Tubular concretions are of two kinds: slender detached ones, which are extremely elongated spindles, and others formed by the separation and arching of limonitic layers along an axis.

Most of the detached tubes are the size of fountain pens, but they have been found up to nearly 3 feet in length and 4 inches in diameter. The length of most large specimens is indeterminable, since only segments are recovered from exposures in embankments. These segments give a false appearance that the tubes are open at both ends, whereas entire specimens always terminate in solid tapering cones and the interiors contain loose aggregates of sand and limonite. The diffusing molecules were fed toward these tubes from opposite directions and normal to the length, which always conforms to the bedding. A partially cemented rodlike aggregate is first developed, later an outer shell, and, finally, a tube results from excessive intergranular secretion and expansion of the wall.

Expansion and separation of crusts from limonitic layers produces planar cavities (pl. 2, *A*) or tubular openings if the arching is definitely linear. Such tubes may be variously angular in section or cylindrical, depending upon the perfection of arching. Numerous tubes with long slitlike, angular, or distinctly cylindrical openings have been found along the upper surface of a large ferruginous bed in the Fort Jackson Reservation near Columbia, South Carolina. Gradations from incipient slitlike cavities to tubular ones are common. Later thickening of the limonitic bed has incorporated many tubes within its mass. Obviously, these concretions grew largely by additions from above, although during the arching process some lateral transfer may have occurred.

Compound tubular concretions originate after the manner of some nodular types except that structure modifies the diffusion of building material in the former. The pictured specimen (pl. 2, *B*) must have first acquired the smaller chamber (note the thinner wall), and the larger chamber later formed beside it. The outer wall of the smaller represents the thickness of the original tube plus additions made by the later one. Rates of growth were not uniform throughout the whole length, for cross-sections vary in size and outline, with numerous corrugations and nodules. The secondary chamber is believed to have resulted from the speeding-up of deposition along one side of the original tube. A new rod-

like aggregate resulted from relatively rapid enmeshing of sand grains; and later with slower deposition it acquired a surrounding wall to be followed by an inner cavity similar to that of the first tube. A repetition of this process would result in polychambered forms. Willcox (1914) has described the published excellent photographs of such polychambered tubular concretions from the Redbank sands in New Jersey. These, like the ones from South Carolina, can be satisfactorily explained by the process of intergranular secretion of limonite.

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GEOLOGICAL NOTES

UNUSUAL VOLCANIC DIKE AND GROOVED LAVA AT AUCKLAND, NEW ZEALAND[1]

J. A. BARTRUM AND E. J. SEARLE
Auckland University College

HOLLOW DIKE

Quarrying operations in the well-bedded scoriae of the cinder cone of Mount Wellington (448 ft.), Auckland, have, since 1926, exposed a nearly vertical dike, which shows several unusual features.

This dike, which in most places is not over 1 foot wide, is characterized by small, irregular, cupola-like extensions. The extensions, which appeared as excavation proceeded, are now, in large part, destroyed. Short apophyses are rare (fig. 1). Near the base of the cone, the dike appears to have been the source of a small flow, a little over 3 feet in maximum depth. The flow is exposed for about 15 yards in a cut, though its full extent is unknown on account of debris. The dike has been traced to within 3 or 4 yards of the flow and almost certainly joins it below the floor of the quarry. From the quarry floor it extends upward for a little over 100 feet. Its upper portions, especially near the cupolas, have a median void, 5 inches in maximum width, but diminishing in a few feet to nothing (fig. 1). On either side of this central cavity there is a wall of solid basalt about 4 inches in width in contact with the scoriae walls; this forms an arched hood over the opening at any cupola (text fig. 1). The inner surface of this wall very commonly shows signs of notable refusion, for in many places it is glazed and coated by drip (pl. 1, fig. 2).

At one place, a later intrusion of basalt, 5 inches in width, has been pushed up in the void of the dike; all that is visible of it at present is a small upward-projecting tongue with typical black glossy chilled skin over its strongly arched surface and on its sides where they make contact with the containing walls of the main dike.

Three curious spiracle-tubes have also been found associated with the dike. One occurred *in situ* immediately above the dike, whereas the other two had obviously fallen from similar situations. The largest is 2 feet, 10 inches in length and 1 foot in maximum diameter at one end and 4 by 1½ inches at the other (pl. 1, figs. 1, 3). These tubes were probably upward extensions of the cupolas.

The origin of these spiracle-tubes is closely bound up with that of the dike. The basaltic magma that was injected into the dike fissure must have been very highly charged below with occluded gas, which, on being freed, converted upper portions of the invading magma into a frothy mixture of gas and liquid. At several points there was an excape of this gas from the upper surface of the dike. Upward movement of the froth of liquid and gas was accompanied by freezing of about 4 inches of basalt to either wall of the fissure. The gases liberated on freezing escaped into the median hollow of the dike, where their combustion developed sufficient heat to fuse the walls of the cavity. The gases, on leaving the dike, fluxed tubular passages through the scoriae for a few feet and welded material adjacent to these passages into irregular cylindrical bodies.

GROOVED LAVA

Three examples of lava with grooves, very similar to those described by Nichols (1938) and by Nichols and Stearns (1940) from New Mexico and Idaho, have recently

[1] Manuscript received October 7, 1947.

been noted at Auckland. One is a block of basalt which has been erupted with scoriae at the Mount Wellington quarry mentioned above; another is a slab of basalt in a lava cavern in the grounds of Auckland Grammar School, Mount Eden; and the third is part of the roof of a cavern in a flow from Mount Eden at Mortimer Pass, Newmarket. The only comparable example of this grooving previously noted from Auckland has been described from a dike in a quarry also adjacent to Mount Eden (Bartrum, 1928).

Nothing is known of the conditions of origin of the Mount Wellington block of grooved lava (pl. 1, fig. 4). A mass of scoriaceous lava was so firmly welded to its grooved surface that, when a cold chisel was used to prise the two portions apart, rupture occurred through the material of the upper block, as indicated in the photograph, and not along the surface of contact. It is evident that, after the formation of the grooves, a mass of hot ejected lava fell upon the grooved surface and had sufficient liquidity to be welded firmly to it. A second small adhering fragment is shown in the left middle portion of plate 1, figure 4.

The grooved lava at Auckland Grammar School appears in a slab 5 by 1½ feet in size. The slab, completely covered by grooves or striations, has fallen from a side wall of a cavern about 12 feet across. The grooved surface is continued in solid lava at the end of the cavern in a fissure with a 45° dip. The grooves have much less depth and are much closer together than those of plate 1, figure 4, so that many are better regarded as striations. The surface of the slab is roughened by close-spaced, tiny, irregular shrinkage cracks, which are approximately at right angles to the grooves. Many cracks are less than 1 mm. in depth, and some have an edge serrated by minute teeth. The cavern in which the specimen occurs is within a few feet of the original surface of a flow of basalt not less than 90 feet in depth, which is well exposed in a quarry close at hand; it appears to represent a "gas blister."

At Newmarket, grooves almost identical with those just described appear on a surface approximately 4 by 3 feet in size, which is part of a thrust plane, dipping 30°. It forms a portion of the roof of a cavern about 5 feet across and 7 feet high, which is located 10 feet below the present surface of a flow of basalt not less than 50 feet in depth, which has come from Mount Eden volcano. This

FIG. 1.—Basalt dike locally with a median cavity, Mount Wellington, Auckland. Main dike on left; a branch on right. The hat rests on scoriae and serves to give the scale.

cavern, like that at Auckland Grammar School, probably is a gas blister in the lava.

The origin of the grooves in the two last specimens is clear from the demonstration of thrust in the occurrence at Newmarket and is similar to that of grooves from McCartys flow, New Mexico, which Nichols (1938) has shown to have been formed by the upthrust from below of semisolid, pasty lava upon the rough surface of upper, wholly solid, cooled rock. It is clear from the details of the surface of the Auckland Gram-

mar School specimen that the upthrust mass must have reached the stage of almost complete solidity when movement occurred; the transverse cracks otherwise would have deepened as cooling progressed.

ACKNOWLEDGMENT.—The writers are indebted to Mr. H. R. Kennedy for the grooved lava from Mount Wellington and also for drawing their attention to interesting features of the quarry at that place.

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PLATE 1

FIG. 1.—End-view of the spiracle tube of fig. 3, showing the fused lining of the spiracle itself.

FIG. 2.—Re-fused glazed surface of wall of cavity of dike of fig. 1. Drip features are clearly visible.

FIG. 3.—Spiracle-tube of agglutinated scoriae, Mount Wellington, Auckland. An opening of the spiracle shows on the right.

FIG. 4.—Grooved lava, Mount Wellington, Auckland.

1
2
3

DISCUSSION

MIMA MOUNDS

CHAPMAN GRANT
San Diego, California

Dr. Victor B. Scheffer published an interesting article (1947) on the origin of the "mounds" which are to be found throughout much of the western plains. The title, *The Mystery of the Mima Mounds*, leaves us to guess whether or not he solved the riddle. In his text Dr. Scheffer is satisfied that they were built by pocket gophers. In an earlier article, which he wrote with W. W. Dalquest (1942), the case is more convincingly stated. His arguments may be paraphrased somewhat like this:

In deep soil the pocket gopher digs his tunnels, lines his underground nest, and lives his life without causing any changes in the landscape. If, however, there is a hard substratum within a foot or two of the surface, his actions are entirely different. A nest site is then dug deep into the hard stratum. This done, the gopher digs radiating tunnels for foraging. He brings a minute excess of soil *toward* the nest site over what he takes *from* it. After thousands of years his descendants have accumulated a "mound" at the original nest site. His progeny has peopled the entire shallow-soiled prairie as thickly as the forage will permit, and this proximity governs the spacing of the mounds as they are now found. Cobbles which occur in the hill are gradually settled by his digging under them to construct a deep nest for his young—safe from wandering bear, wolf, and wildcat! In excavating his foraging tunnels between mounds, he is motivated by a less vital instinct, so, having no reason to go deep to protect his young, he merely passes around any cobble encountered, and, because the soil is gradually moved to the hill, cobbles are exposed and strew the intermound spaces. All mounds are gopher-made whether gophers now inhabit the area or not. Shallow groundwater may have the same effect as a hard substratum.

The following points made by Dr. Scheffer (1947) are followed by the writer's criticism.

1. At certain places [the gophers] dug deeply into the gravelly subsoil in order to make nest chambers.

Years of experience with the pocket gopher has convinced me that its nest chamber is no deeper than most of its burrow. Dr. Scheffer's figure 2 illustrates the shallowness of the nest.

2. Because of depth, the nest chambers are ". . . well protected from prowling bear, wolf or wildcat."

The chief protection of the gopher, like that of the rabbit, is its fecundity. In addition, it tries to stay underground and keep its burrow well plugged. Dr. Scheffer apparently thinks that predators seek the young in preference to adults. The number of nests destroyed by bear or wolf must be very small compared to the adults destroyed by these two animals. The number of nests dug out by wildcats is 0. A wildcat does not dig. The real vertebrate enemies of the gopher are snakes, owls, hawks, and weasels. Disease and parasites, drowning and starvation, are the effective checks on this rodent—not bears.

3. "Areal spacing of the nest chambers corresponded to the size of the 'territory' of each animal. The center of an old territory now marks, we believe, the center of a modern mound."

The territory of a pocket gopher does not normally radiate from a center but is, instead, a rather long, narrow figure, or a line. Nowhere are territories found as close together as are the mounds, or as evenly spaced. The evenness of distribution is too great in that it would require a vast pasture, rich enough to support an evenly concentrated population. In reality, any such expanse would contain areas of poor pasture, where mounds would have been spaced farther apart or would be missing.

4. "When the animal ran into a large boulder it undermined the obstruction and allowed it to settle."

This assigns a complicated purposeful action on the part of the gopher in excavating its nest

site. There is no evidence to support this statement. The use of the term "boulder" in many places in Dr. Scheffer's article is incorrect. The author means "cobblestones."

5. "Thus, we now find, at the base of most mounds, a concentration of coarser materials."

Dr. Scheffer tries to prove a point uncalled for by his own theory. His gophers are supposed to have started upon a flat plain and to have ultimately piled up mounds containing pebbles "no larger than walnuts." He now attempts to prove how the gophers got "boulders" *out* of mounds which could not have contained anything larger than a walnut in the first place!

6. According to Dr. Scheffer, when the gopher dug tunnels for foraging, it was driven by less powerful instincts than that of nestbuilding, so, when it encountered a rock, it simply passed around it. I do not believe that a gopher acts differently toward an obstruction in a runway or a nest site.

7. ". . . shoving dirt along as it went."

Apparently the object of this statement is to prove that gophers might push more dirt in one direction than in another. Actually, gophers make "spoil" dumps at more or less regular intervals along their rather straight line of burrowing. There is no evidence that the dumps are placed in any position or direction other than that dictated by convenience.

8. "Thus, we find plainly exposed in the intermound hollows large boulders that were doubtless at one time buried in the topsoil."

This would be possible only if the gophers continually made their spoil dumps toward a center. There is no reason to believe that such was the case. They certaintly do not do so at this time.

9. ". . . 'mound roots' . . . are simply abandoned gopher tunnels now filled with black silt. . . . They call to mind the peculiar devil's corkscrews . . . [of] Nebraska . . . [which] are now generally believed to be the casts of burrows of extinct rodents."

In a footnote Dr. Scheffer refers to A. L. Lugn (1941, p. 673). Lugn, however, stated: ". . . vegetal origin is believed demonstrated . . . [as the cause of the corkscrews]."

10. "Where [a] nesting chamber collapsed [it] caused a depression at the crest of the mound, a characteristic feature of many of the mounds. . . ."

Dr. Scheffer illustrates everything else, even including a Fresno scraper, which is used to grade down the mounds for agricultural purposes, but omits illustrating this special depression. I have never seen such a depression and would have appreciated a picture of one. A nest chamber is the size of the bowl of a derby hat or smaller. It is never reused or enlarged, to my knowledge. Gophers do not seek out high ground for nest sites.

11. "In fancy, it is easy to picture the start of a Mima Mound."

Without proof or reason to believe that gophers move an excess of soil toward a common center, it is impossible to fancy the beginning of a mound.

12. "It is less easy to account for its [the mound's] growth."

I see no difference between the inception and the later growth of a mound. Once started, I can visualize its continued growth. Why the gophers should stop building at a certain size might be a problem; but then, muskrat nests are of approximately the same size.

13. "For reasons that may never be known, the gophers carried more dirt towards the nest than away from it."

I agree with the first part of this sentence but not the last part. In fact, I am speechless at this admission and wonder why the article was written.

Dr. Scheffer's article ends with some "conclusions" which I treat similarly to the body of the article:

14. ". . . mounds are distributed . . . exclusively in the range of the pocket gopher."

According to his own statement: "There are no gophers on the Mima Prairie."

15. "Burrowing animals with habits similar to those of the gopher, namely the ground squirrel (*Citellus*) and the mole (*Scapanus*) . . . are not pertinent to the formation of mounds. . . ."

According to his first conclusion, there are no gophers in the Mima Prairie, so they would not be pertinent either. Dr. Scheffer seems to propound a theory that the range of a species is

rather permanent. Animals as well as plants migrate with changing conditions.

I am amazed at the statement that the burrowing habits of the squirrel, mole, and pocket gopher are "similar." I cannot name three better examples of diametrically different uses of the earth by digging animals. The ground squirrel lives in colonies, burrows only for protection, and forages above ground by day. It has good eyesight, moderately developed nails for digging, and does not use its teeth for digging. The spoil is deposited at the mouth of the unplugged burrow. The mole, nearly blind, possesses a remarkably specialized body for forcing its way along under the sod in search of worms and insects. It seldom burrows, does not leave spoil dumps along its unplugged tunnel, and does not forage above ground. The pocket gopher plugs his burrow and can feed only over a radius of his body length around a forage hole—never completely emerging. (The young and males do travel above ground at certain seasons at night to start a new territory or to find a mate.) Its teeth and toenails are modified for digging and its pouches for carrying soil.

16. "... mounds are found only where ..a thin layer of workable soil [overlies] a dense substratum."

Dr. Scheffer quotes Vernon Bailey as stating that mounds occur in southwestern Louisiana. There is no hard substratum there.

17. "... in deep sandy soil ... [gophers] never form Mima-type mounds."

There is no proof that they produce mounds in shallow soil either. There are great areas of mounds where no gophers occur and vice versa.

18. According to Dr. Scheffer, the mounds are not deposits since they are unoriented and occasionally occur on slopes.

Dr. Scheffer's figure (1947, p. 286) shows that the mounds have a marked orientation. The fact that the mounds differ in texture from their bases proves that they were *built* by some means.

19. According to Dr. Scheffer, the mounds are not due to erosion because the interspaces are frequently closed depressions.

The most obvious disproof of dissectional residue is that the substratum differs from the mounds.

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MIMA MOUNDS: A REPLY

VICTOR B. SCHEFFER

U.S. Fish and Wildlife Service, Seattle, Washington

Major Grant believes that gophers behave in one way, and we[1] believe that they behave in another—or we admit that we do not know exactly how they behave. I have plainly stated (1947, pp. 293, 294) that our evidence is indirect; that we have not seen gophers building a giant mound; that we do not know whether mound building is a contemporary or a historic process; and that we do not know whether the stimulus for mound building is a hardpan or a high water table or both.

Our main contentions are (1) that mounds of the Mima type occur only within the range of

[1] In 1942 Walter W. Dalquest and I developed the theory of origin of the Mima Mounds by gopher activity. Since Mr. Dalquest is in Mexico and unable to enter the present discussion, I am taking the liberty of defending his views as well as my own.

gophers, living or extirpated, and (2) that only a living, adaptable force, not a physical agency, could have produced the Mima-type mounds out of widely varying materials and in widely varying environments from Mexico to Puget Sound. We note that Chapman Grant does not propose an alternative theory for the origin of the mounds.

In his introduction Major Grant has paraphrased our arguments quite well. We disclaim the statement: "All mounds are gopher-made whether gophers now inhabit the area or not." There are, of course, many kinds of mounds. We claim only that the Mima-type mound or pimple mound, as illustrated in our article, is gopher-made. Furthermore, the only place on the West Coast where we have seen Mima-type mounds unassociated with living gophers is Mima Prairie, a small opening of perhaps 10 square miles. Major Grant, later in his paper, emphasizes the fact that there are no gophers here. As we have explained (1942, p. 81; 1947, p. 293), the absence of living gophers on this specific prairie is unimportant. Rather than selecting Mima Prairie as the type locality of the pimple mounds, we could as easily have selected Tenino Prairie, where there *are* mounds inhabited by living gophers, 1 mile southeast of Mima Prairie.

We shall attempt to answer Major Grant's criticisms, numbered for easy reference, as follows:

1. The depth of a gopher nest varies. The nests with which Major Grant is familiar may be shallow, but

> . . . on the gravelly prairies of western Washington the feeding runs of [the gopher], as they approach the vicinity of the nest, descend almost vertically to depths of 2, 3, and even 5 feet. . . . In excavating four burrow systems of this species, the writer found the nests at depths of 26, 29, 34, and 36 inches, respectively [Scheffer, 1931, p. 13].

2. The specific enemies or adverse conditions that a gopher avoids in nest building are unimportant in our discussion. The pertinent facts are that a gopher always builds a nest, the nest is the focal point of the home territory, and the nest is deeper than the average foraging runway. Fish and Wildlife Service records of stomach examinations show, however, that gophers *are* eaten by bear, wolf, and wildcat; but, again, these facts are unimportant.

3. Major Grant raises an interesting question in connection with the shape and spatial relations of the foraging territory. It is true that the foraging territory, or burrow system, is more linear than circular, *at any given time*. Enough burrow systems have been excavated to prove this point. The burrow system is constantly changing, however, as the gopher searches for plant roots. New tunnels are made, old ones are filled; a gopher dies and another takes its place; subadult gophers leave the nest and seek new territory. We believe that the effect over many gopher generations is a honeycomb-like spacing of the mounds.

In this connection the areal distribution of other mammals is significant. On the Pribilof Islands, Alaska, the male fur seals gather in the spring, each taking up a territory on the beach and jealously guarding it from newcomers. The seals are not spaced with the regularity of checkers on a board, and yet they are certainly not spaced at random. Here we have a visible example of the fairly uniform spacing of family territories. We cannot see the spacing of gophers because they live underground, but we can infer that the individual territory tends to be circular or, more precisely, hexagonal in shape. The tightness or looseness of the network of home territories probably varies with the kind of soil and vegetative cover; that is, a gopher family requires more foraging ground where food plants are scarce than where they are plentiful.

In previous accounts we have stated our belief that the mound is developed around the center of an old nest burrow. We do not mean to imply that each mound is still the hereditary castle of a family of gophers. At any given time some mounds are occupied, and others are not. Were all the mounds occupied at once, Major Grant could reasonably feel that the gophers were overcrowded.

4. We did not state or imply that the gopher uses reasoning power. When it moves dirt from the side or top of a boulder, the boulder remains at rest. When it moves dirt from beneath the boulder, the boulder tends to settle. The evidence is a layer of coarser materials at the base of the Mima-type mound.

5. The intermound cobbles, or boulders, on the Puget Sound prairies were not moved out of mounds by gophers. They are more or less *in situ*, although many of them have been bared by the removal of silt gravel.

6. We feel that this is a matter of opinion.

7. Major Grant has understood us correctly. We believe that, where soil and climatic conditions are favorable to mound building, gophers *do* push more dirt toward the nest. In addition to mounds, of course, one can see the small spoil

heaps or gopher hills scattered on and between the mounds.

8. It is true that gophers do not everywhere make their spoil dumps toward the center. We believe, though, that over periods of time, in the shuttling of dirt as the gopher digs for plant roots and for nest and food-storage chambers, there is a differential movement of materials favoring the growth of the mound.

9. We inadvertently cited Lugn. We should have cited C. Bertrand Schultz who, in 1942, stated that "most palaeontologists now believe . . . that Daimonelices are the casts of rodent burrows."

10. A shallow depression occurs on the top or flank of many mounds on Mima Prairie. On this prairie, the reader will recall, there are no living gophers. We interpret the depression as the collapse of an old nesting chamber somewhere in the mound. It may, however, represent the recent activity of moles or livestock. J Harlen Bretz (1913, p. 101) referred to "occasional . . . sunken areas a foot or so across on these mounds. . . . The small sunken areas are so recent that the sod has not healed over the marginal cracks."

Major Grant states that "gophers do not seek out high ground for nest sites." We have been given two photographs taken in Texas, showing mounds sliced open to reveal nest chambers well above the surrounding ground level. Here winter flooding evidently obliges the animals to build their nests out of danger. Pennoyer F. English (1932, p. 127, pl. 9) has published a photograph of a similar Texas mound, with the statement that the gopher here "builds its nest not deep in the ground but in an enormous mound."

11. We find it easy to fancy the beginning of a mound as a center of activity in the vicinity of the nest. Others, with equal freedom, may fancy the beginning of a mound as a platform on which the gopher attempts to raise its nest out of the mud at a certain season.

12. The size of a Mima-type mound in a particular locality probably depends upon many factors. We are more concerned, though, with establishing the fact that the mounds are of gopher origin than with the ultimate size to which the mounds may grow. The industry of the gopher as a mover of soils is perhaps greater than many realize. According to Lincoln Ellison (1946, p. 113):

> In what is considered to be a representative part of the subalpine zone of the Wasatch Plateau in central Utah, annual displacement of soil to the surface by pocket gophers was found in 1941 to be at least 5 tons per acre and to cover 3½ per cent of the surface. The base population of pocket gophers is estimated to be somewhere between 4 and 16 animals per acre.

13. See No. 3.

14. See our introduction, paragraph 3.

15. We do not "propound a theory that the range of a species is rather permanent." In fact, we once published a paper describing the migrational history of gophers (1944, pp. 308–333, 423–450).

Use of the word "similar" here is a semantic privilege. The mole, ground squirrel, and pocket gopher are similar in that they make tunnels and throw out excavated soil in mounds.

16. We have clearly posed the question (1947, p. 294): "Does ground water at certain times of the year and in certain localities act in the same way that a soil hardpan does. . . ?" We have not seen the mounds of Louisiana, but, from the evidence of aerial photographs and from correspondence with Vernon Bailey, we believe them to be of the Mima type. *If* they actually are of the Mima type and *if* there is no hard substrate there, the water table may act as hardpan does on certain other mound prairies.

17. Major Grant states that "there are great areas of mounds where no gophers occur and vice versa." We have pointed out that the absence of living gophers in Mima-type mounds does not invalidate the theory of their origin in past years by gophers. We have also pointed out that there are many smooth prairies where gophers are living but where conditions do not favor the formation of mounds (1942, pp. 81, 84; 1947, p. 293).

18. Bretz's map, which we used as a figure (1947, p. 286), perhaps suggests slight orientation. Bretz himself stated that, while there is commonly an elongation of the mound, it "does not conform to any definite orientation" (1913, p. 83).

Major Grant discusses orientation, but he does not comment on our point that the mounds occasionally occur on slopes. Here is a phenomenon difficult to account for, unless one accepts the theory that the mounds are built from within, by animals. We quite agree with his statement: "The fact that mounds differ in texture from their bases proves that they were *built* by some means."

19. Major Grant's criticism is not clear.

ACKNOWLEDGMENT.—Dr. J. Hoover Mackin has read the manuscript and offered helpful suggestions.

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PETROLOGICAL NOTES AND REVIEWS

RECENT CONTRIBUTIONS TO THE GRANITE PROBLEM

TOM. F. W. BARTH
University of Chicago

During the last one hundred and fifty years the question of the genesis of granite has frequently reappeared as the chief subject of discussion among geologists and geophysicists. Among the recent contributions are those of R. Perrin and M. Roubault, P. Niggli, M. Reinhard, E. Raguin, and H. G. Backlund.

Two articles published in English (Grout, 1941; Read, 1943, 1944) are presumably easily available and are not reviewed here.

Om granit och gnejs och jordens ålder ('On Granite and Gneiss and the Age of the Earth'). By H. G. BACKLUND. ("Kungl. Vetenskapssocietetens. Arsbok, 1947.") Uppsala, 1947. Pp. 67.

Backlund's book, one of the most recent, is reviewed first because Backlund, probably more than anyone else, was responsible for reviving the discussion of the granite problem in 1936 (pp. 293–347) by propounding a granitization theory disclaiming the primary, magmatic character of the rapakivi granites and similar rocks. For more recent references see Backlund's papers of 1938 and 1946.

It is a puzzling fact that the mineral assemblage of granite cannot be duplicated in laboratory furnaces, although the frequency and large areal distribution of granites in orogenic areas of all ages indicate that they form with great ease in nature.

It is of genetic importance that most ore deposits, oxidic as well as sulphidic, are intimately associated with granites in the upper parts of the earth's crust. But the exact relationship is obscure—often the practical prospector has more success than the professional geologist in discovering new ore (Rastall, 1945).

Pegmatites are closely related to granites. Less than fifty years ago, a leading scientist, A. E. Nordenskiöld, said that no geologist in his right mind could believe in the formation of pegmatites from molten solutions. Subsequently, they were explained as late crystallization products of granite magma. Now great quantities of volatiles, especially water, are believed to be instrumental in their formation (pneumatolysis). Some pegmatites carry rare elements. In this respect they are analogous to ore deposits, especially where large parts of them consist of only one "rare" mineral (petalite, amblygonite, pollucite, beryl, or others). The distribution of such minerals is very irregular, and many pegmatites are quite "sterile."

Migration of elements from the granite across the boundary into the adjacent rocks has taken place, contrary to the opinions of Rosenbusch and his school. The granite is not a passive carrier of heat; it is an active vehicle which conveys heat and material, sets up temperature gradients, and mobilizes gases and vapors and other chemical ions, thus inducing minerochemical changes in vast areas far outside the contact face (metasomatism). The changes take place volume by volume. Homogeneous mineral assemblages (often monomineralic) may form, which are lower in silica than either the granite or the adjacent rock. They represent geochemical "culminations," are called "diabrochites" (Backlund, 1943; Reynolds, 1947), and have often been misinterpreted as truly magmatic.

According to the "reaction principle" developed in the laboratory, the early products of crystallization cannot become assimilated by the rest magma; but the gradual disappearance of aggregates of early crystals and of basic inclusions in all granite areas is well known. The cations Fe and Mg show a tendency to migrate. The evolution of the series: greenschist → amphibolite → metabasite, which is closely connected with the gneiss-granite problem, cannot be explained through the action of hot magmas from great depths.

The "ichor" of Sederholm is redefined and

called "emanation" (Wegmann, 1935). If a rock, A', is granitized into B', the reaction in its first approximation may be written as follows:

$$A + x = B ,$$

in which A and B are the specific gravities of educt and product, respectively, and x represents the quantity of the emanation. The relation of x is as follows:

$$x = e_1 - e_2 - a_1 ,$$

in which e_1 is introduced emanation, e_2 is the fraction of e_1 not fixed in A', and a_1 is the fraction given off by A' in the reaction $A' \rightarrow B'$. The emanation is of pulsating character and represents a migration of ions facilitated by lattice disorders, substitutions, polymorphic inversions, lattice deformations, etc. The process is very slow even in comparison with exogenic processes, such as denudation, erosion, etc.

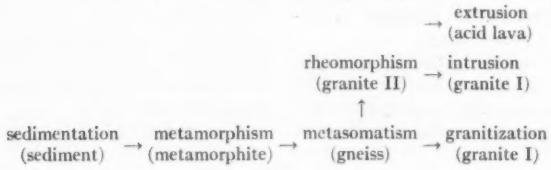
Backlund is a staunch advocate of the uniformitarian view and claims that all the extensive and still largely undifferentiated pre-Cambrian gneiss areas represent relics of old mountain chains. (There have been between twelve and fifteen different orogenies in the history of the earth.) During each orogeny, intense granitization took place. Large parts of mountain chains that originally were made up of normal sediments were replaced by granite and gneiss, regardless of age, in all geological eras. This was not a replacement of solid rock by molten magma or a melting of the sediments by magmas, for the amounts of missing sediments are much too large, the volume relations too acute, and the replacing rocks too homogeneous. The various radioactive age determinations (made on granitic or pegmatitic minerals) simply indicate the time of the several orogenies. But there are always sediments older than the orogeny, even biogenic sediments. Thus the total age of the earth cannot be determined in this way.

Sediments of granitic composition (arkoses) are most easily granitized (corresponding to small values of x and a_1). If the chemical differences are large, then a_1 will be large, and the original rock will long resist granitization. This corresponds to the following (relic) series in granitization (in order of increasing ability to survive): (1) mica schist, (2) quartzite, (3) limestone, (4) basites, (5) ores.

Of particular interest is the distribution of the trace elements, which are said to harmonize with a diffusion differentiation but not with a magmatic differentiation (Bray, 1942; Sahama, 1945*a*, 1945*b*; Sandell, 1943; Shimer, 1943).

The continuous succession of granitizing processes may be presented as shown below. Backlund praises Sederholm, who, although he was a pupil of Brögger and Rosenbusch, undertook the further development of the granitization theory after the French had become silent at the beginning of the present century. Sederholm's grand role, in the face of united opposition for several decades, cannot be overrated. Today Sederholm's ideas are pushed further than he ever had supposed possible.

GRANITIZING PROCESSES



Le Granite et les réactions à l'état solide. By R. PERRIN and M. ROUBAULT. (Bull. du Service Carte Géol. de l'Algérie 5e sér. [Petrographie] No. 4.) 1939. Pp. 182; figs. 8; pls. 6.

The authors are worthy successors of the splendid French school of 1847 and of the skilful petrographers of the eighties and nineties: Michel-Lévy, Termier, Barrois, Lacroix, creators of the striking *tache d'huile* and *colonnes filtrantes* analogies for describing the granitization processes. In 1937 they published a book giving the underlying physicochemical theory of the reaction and the diffusion processes in the solid state and the general geological conclusions derived from them. The authors are convinced that the existence of selective diffusion is the clue to all problems of metamorphism. The origin of granite is explained in this way.

Rocks form by reactions between solids or by crystallization of a magma. The problem is to find out which process has been active in the formation of any given rock.

By thoroughly searching the geological literature, the authors have found the following statements in favor of a magmatic origin of granite. They are all rejected, however.

1. *Order and temperature of crystallization.*—The authors think that irregularities in the order of the elements and certain phenomena of zoning are incompatible with crystallization from a melt.

2. *Injection "lit par lit."*—The hypothesis, in accordance with Bowen's reaction principle, of a residual liquid which is mechanically injected into schist layers without dissolving the basic minerals is, according to these authors, contrary to observations. They conclude, therefore, with Michel-Lévy, that the phenomenon is metamorphic in origin.

3. *The phenomena of inhibition and soaking.*—The development of granitic minerals in enclosed blocks is best explained by reaction in the solid state.

4. *The existence of dikes and apophyses.*—This is given a long and interesting discussion with numerous references to the observations and interpretations of many leading geologists. Despite the subjective impressions of earlier observers, the authors conclude that the dikes and apophyses are not proof of a liquid granite. They merit renewed and precise study, however, and individual consideration of each case.

5. *The transition of granite into microgranite and rhyolite.*—Are the changes in texture due to a change of the rate of cooling of the magma or to subsequent recrystallization? The authors favor the latter hypothesis.

6. *Homogeneity of granitic massifs.*—In the opinion of these authors, homogeneity does not support the differentiation theory of Bowen. It should be added that the homogeneity is only relative: analyses from various parts of a massif are usually similar but not identical.

7. *Presence of liquid inclusions.*—Liquid inclusions and granites formed in the solid state are not incompatible.

Among the additional problems which are thoroughly discussed are the digestion of dikes, the gradual transition of schist or gneiss into granite, the *mise en place* of the granite, reactions in the solid state in massif rocks other than granite, and the possibility of large-scale solid diffusion.

In summing up, the authors believe that the evidences in favor of a liquid granite in all cases rest on "subjective impressions" and on analogies associated with the molten state. But detailed studies prove that reaction in the solid state can make, and has made, similar rock bodies. The authors were unable to discover a single clear case in which a granite showed a magmatic mode of origin. On the other hand, numerous granites, varying greatly in geology and in mode of occurrence, show evidence of formation in the solid state.

The book is a store of information; it is stimulating and full of new ideas. It is logically and clearly written, and there are no wild speculations. Each statement is carefully considered and supported by thoroughly checked physicochemical facts. It is a pioneer work of great value to geological thought.

"Das Problem der Granitbildung." By P. NIGGLI. (*Schweizer. min. pet. Mitt.*, vol. 22). 1942. Pp. 84.

It is almost impossible to give a review of Niggli's paper. It is in itself a review, although of great length. With the help of very rich historical material, the development of the various notions pertaining to the genesis of granites is discussed.

The modern controversial subjects have received fair treatment, in that long sections (several pages and more) of a great number of contemporary writers are quoted verbatim in the original language.

But there can be no mistake about the point of view taken by Niggli himself. His paper is a clear vindication of the purely magmatic origin of granite. He has no use for concepts like granitization, "intergranular films," or "migmas"; even the term "migmatite" as a rock name is grudgingly accepted. He points out that the views put forth in his paper are very similar to those expressed by Grout (1941), whom he quotes at length and with approval.

"Die leukogranitischen, trondhjemitischen und leukosyenitischen Magmen und die Anatexis." By P. NIGGLI. (*Schweizer. min. pet. Mitt.*, vol. 26.) 1946. Pp. 34.

The attitude adopted in this later article is that each granite should be considered on its own merit, and its particular origin discussed. In the origin of granite there is no "either-or." Niggli is now willing to accept the existence of at least three kinds of granite: "magmagranit," directly crystallized from a magma; "metagranit" (as used by Kranck in Wegmann and Kranck, 1931), formed by simple recrystallization of arkose and similar rocks; and "migmatit-

granit" (as used by Kranck in Wegmann and Kranck, 1931), representing the end-product of the metasomatic series: sediment—metamorphite—ultrametamorphite—migmatite granite.

The following definitions, which are partly adopted from Rittman (1942–1945), are proposed:

Migma is a silicate mass, generated through partial deliquescence of rocks, containing relic minerals (palaeosoms), and unable to be intruded like a magma.

Syntectic magma has changed its composition through assimilation.

Palingenic magma is of migmatic origin.

Hybrid magma is the result of the mixing of two or more magmas.

Parautochthonous magma generates and congeals more or less in the same place.

Allochthonous magma generates at some place other than that where it congeals, e.g., at great depth.

Niggli's superior insight and intimate knowledge of the subject make his reviews sources of information which should be consulted by all students of the controversial granite-gneiss problem.

Über die Entstehung des Granits. By M. Reinhard. ("Basler Universitätsreden" 16.) Basel: Helbing & Lichtenhahn, 1943. Pp. 38.

The fundamental queries of the magmatic petrogenesis are: How did the individual rocks and rock series develop, and why is granite absolutely dominant among the deep-seated rocks, while basalt dominates among the extrusive rocks?

There are three different ways to form a granite:

1. A residual granitic liquid will develop through fractional crystallization of a basaltic magma.

2. The granitic rest magma, rich in volatile constituents, is eventually replaced and succeeded by a fluid phase high in alkalies and silica. This phase will react with the minerals of the congealed granite and partly change them into new minerals. It will also diffuse into the adjacent rock and react with its minerals. Sandstones and shales may thus be changed into rocks, which in their mineral composition and structure are identical to granite.

3. The deeper parts of all orogenic zones are dominantly granitic in composition (massive granite, schistose gneiss, augen gneiss, layered gneiss, injection gneiss, migmatites, every transition from truly magmatic rocks to metamorphic sediments). This is the great melting-pot. The process of melting or solution is the opposite of fractional crystallization. The material that crystallizes last will go into solution first. Not wholesale melting, but a differential anatexis, takes place, with formation of a granitic ichor, or migma, which subsequently soaks and permeates the whole rock complex (the name "migma" was coined by Reinhard in 1934).

It is usually impossible to determine the mode of origin of a granite body because the physical and chemical conditions deep in the lithosphere are very inadequately known.

Juvenile or palingene? Magmatic or metamorphic? To the first query we have no answer —it is a question of belief, not of science. We should not contaminate our science with useless discussions but should show tolerance. To the second query we may find a solution through careful studies in the field and in the laboratories. But the question is not rightly presented. It is not "either-or." Most granites are of mixed origin, and the problem is to establish the extent to which they are magmatic or metamorphic. For such studies our conservative petrographic classification is not wide enough. The author favors a fourfold classification: igneous, migmatic, metamorphic, and sedimentary (Barth, in Barth, Correns, and Eskola, 1939).

Studies for twenty-five years in Wallis and Tessin have demonstrated that rocks which were first regarded as orthogneisses and granite gneisses actually are the results of metasomatic processes. The objection of Bowen, that it is easy to invoke "gaseous transfer" because it may explain everything, and of Niggli, that a general gassing and emanation theory is uncontrollable, do not constitute arguments against a prevalence of metasomatic processes.

Reinhard's book gives the full historical background of all these ideas and is a dignified, objective, and logical contribution to one of the most fundamental problems in contemporary geology.

Géologie du granite. By E. Raguin. Paris: Masson & Cie, 1946. Pp. 211; figs. 46.

Because of the war the book by Perrin and Roubault did not get a good distribution outside France. But in France it was known and

naturally met with some opposition. Raguin's book testifies to this.

Raguin thinks that the geology of granite, which is defined as an "eruptive" rock, is of fundamental importance for both ore geology and orogenesis and consequently for the study of the evolution of the deeper zones of the globe. The author draws his knowledge from many sources, and his bibliography includes 126 references from many countries.

However, the physicochemical point of view is put aside; there are no chemical analyses, diagrams of differentiation, or discussion of laboratory experiments. The geological viewpoint prevails, that is, the viewpoint of the "naturalist" who is interested in the crust of the earth.

The book starts with a clear, concise description of the minerals of granite, order of crystallization, structure and texture, and classification of granites, followed by a discussion of the diversity of granite, which suggests a diversity of origin.

There are two types of granite: anatectic and intrusive, bridged by transitional types. Anatectic granites may grade into gneisses and migmatites; intrusive granites form batholiths or other large massifs.

The structural behavior of granitic bodies is adequately treated, including schistosity, foliation, cleavage, jointing systems, and general tectonics. Alteration of granites, crushing, and mylonitization are also amply discussed.

In the formation of granite, great importance is placed on assimilation by the magma. The differentiation of granitic magma is also discussed, but the author fails to explain the relatively great abundance of granite magma compared with any other type of intrusive magma. Because granitic lavas (rhyolites, etc.) probably make up less than 1 per cent of all visible extrusive rocks, the question must be answered.

Dike rocks associated with granite (aplites, pegmatites, pneumatolytic veins, lamprophyres, and porphyries) are described.

The chapter on the metamorphism of granite is very interesting. The underlying ideas are those of the great French school of metamorphism (Termier, Michel-Lévy, Barrois, etc.), supplemented by the work of the Fenno-Scandian school (Sederholm, Holmquist) and the Swiss geologist, Wegmann. From his wide readings the author also incorporates important conceptions from Becke, Harker, Niggli, and Sander, thus arriving at a polished and consistent picture of the metamorphism. However, he rejects the possibilities of reaction and diffusion of chemical substances in the solid state, ideas that have been recently and independently presented in France by Perrin and Roubault, in Great Britain by H. H. Read and Doris Reynolds, in Scandinavia by Backlund and by the petrographic school at Oslo.

The discussion of the intimate connection between granite and orogeny is illuminating and fascinating. Wegmann's ideas of migmatization and granitization of the lower levels of the crust are engagingly described and contrasted with Suess's *Intrusions tektonik:* "There is no simple fusion at the depths of the geosynclines, the phenomenon is larger and more complex. The depths of the earth are in constant evolution as is the surface, and orogeny simply represents the surface manifestations of this evolution."

Granitic volcanism and granitic plutonism are often, but not necessarily, connected. What does it mean? Is it accidental or caused by laws of fundamental importance?

The granite in the crust of the earth is the subject of another chapter of outstanding interest. Granite forms in the crust by refusion (=migmatization), and by differentiation of gabbroic magma at great depth. "Granitization" is one of the principal functions of the crust because by far the largest parts of the crust are granitic. Granitization is not uniform and continuous; it works in cycles of increasing intensity. Because the nature of the deeper shells of our planet is inadequately known, the limits and the full significance of granitization cannot be stated.

The ore deposits of granitic relation (including uranium and thorium ores) are classified, described, and their mode of origin is interestingly discussed.

The last chapter is concerned with the problems of the formation and the *mise en place* of granite. Although the metamorphic (or metasomatic) mode of origin is given serious consideration on the basis of recent writings by Perrin, Roubault, and Backlund, the author concludes that granite passed from a liquid into a solid state for the following reasons:

1. Temperature of formation is relatively high.
2. Order of crystallization is parallel to Bowen's reaction series.
3. Apophyses and veins of granite occur in adjacent rocks.
4. Granite grades into other massive rocks like syenites, diorites, and others of known magmatic origin.

5. Inclusions of the adjacent rock occur "swimming" in granite.
6. Intrusive massive granites sharply cut sedimentary layers.
7. There is evidence of granite formed by differentiation of a basic magma (Sudbury).

But the author emphasizes that the granitic liquid need not always be an ordinary magma; he believes in an "ichor" whose intimate (mechanical?) mixing with the pre-existing rocks gives birth to migmatites and subsequently to granites. Thus granite is often believed to have formed *in situ* (but the author does not enter into the problem of the volume relations). The granitization of a certain part of the earth's crust is partly an alkalinization, partly a homogenization, the result being the individualization of a granitic magma.

This book is an excellent treatise of the geology of granite; it should be read with equal profit by both the student and the professional geologist. It treats the subject clearly, objectively, and logically and sets up an excellent standard for a textbook. It is stimulating and contains a wealth of information. No doubt the geology of granite is one of the most fundamental subjects in geology; it will expand the domain of the geological sciences which are now too strictly limited to the surface of the earth.

The best praise I can give the book is that the "pontifs" (Bowen, 1947, p. 265) will denounce it as radical and the "soaks" will find it reactionary.

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REVIEWS

Igneous Minerals and Rocks. By ERNEST E. WAHLSTROM. New York: John Wiley & Sons, 1947. Pp. vii+367; figs. 135; tables 19. $5.50.

The sequence in which the author presents his material is peculiar. The leading principle, if any, appears to be to make it the opposite of the way nature does it. It is preposterous to discuss the minerals serpentine, prehnite, chlorite-mica and olivine in the order stated and then switch back to zoisite. In like manner the author discusses the rocks in an inverted order. The book is purely descriptive and pays little attention to genetic relations; but that is no excuse for starting with granite, followed by pegmatite, adamellite, tonalite, and quartz gabbro in the order named. Because nature does this, generally speaking, in the opposite direction, it is obsolete to follow the German taxonomers of the last century. The fact that they started it is no reason for our sticking to it.

The book is spotty. While a good description of the optical determination of the plagioclases is offered (although the important high-temperature plagioclase series of Koehler and Tertsch [1942] is neglected), the pyroxenes and the olivines are in this respect treated as stepchildren. The book either should or should not give the necessary data for optical determination of the most important mineral series. I think it should, and I think, furthermore, that it could have been presented without any expansion of the text. The alkali feldspars are poorly treated. Orthoclase, $(K,Na)AlSi_3O_8$, is shown to exhibit variations in the extinction angles but not in the refractive indices. Microcline, with the same formula, exhibits variations in the refractive indices but not in the extinction angles. And sanidine, again of the same formula, differs from both in showing variations of both these properties. Since the alkali feldspars form one of the most important mineral series in nature, it is essential to present them correctly. The student by reading this book (unless he has a teacher who knows better) will become confused and completely fail to grasp the significance of any of these important minerals.

Many minerals are presented by a definite formula, although great variations are claimed in the optical properties, without any reason being given for this peculiar behavior. This is always confusing, but it is particularly so where extended series of solid solutions are treated. For example, data on tremolite and actinolite are presented as follows:

$Ca_2Mg_5Si_8O_{22}(OH)_2$, $\quad a = 1.599–1.613$,
$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$, $\quad a = 1.614–1.628$.

Apparently, the pure magnesium tremolite was able to show just as large optical variations as does the mixed crystal series. The upper limit of index β in tremolite is given as 1.671, which certainly must be a misprint. But I cannot even guess which figure the author had in mind, for the pure Mg-tremolite should show no variation at all.

Antigorite, serpophite, and chrysotile are shown to have different optical properties but exactly the same chemical formulas. The student must necessarily conclude that he has a case of polymorphism, like that of andalusite-sillimanite, the formula presentation of which is strictly analogous. Talc is correctly given as $Mg_3Si_4O_{10}(OH)_2$; but antigorite, serpophite, and chrysotile are not allowed to have any (OH)-groups in their formulas. Prehnite has (SiO_4)-groups but no (OH)-groups; epidote, however, has both (SiO_4)-groups and (OH)-groups. Inconsistencies like these should *never* occur in a textbook.

Modern data are often neglected. Larsen's lectures that Wahlstrom heard before the war are not necessarily modern in 1947: biotite is not categorically monoclinic—hexagonal and trigonal members are known (Hendricks, 1939). On the other hand, the "modern" ideas about the interchange of Al and Si are given a mystical power in, e.g., nepheline, which is presented as $(Na,K)(Al,Si)_2O_4$. I do not see how Al:Si can differ from unity in this formula. $(K,Na,Ca)_{0.8-1}(Al,Si)_2O_4$ would be correct.

Cordierite can no longer be presented as $(Mg,Fe,Mn)_2(Al,Fe)_4Si_5O_{18} \cdot H_2O$. Certainly, this formula cannot account for the great variation claimed for the indices of refraction (β = 1.538–1.597) figures, which are also given in the Determinative Tables. The variation in the in-

dices are mainly due to "stuffing" of the lattice with alkali ions. Cordierite, like beryl, has a structure containing $(Si_6O_{18})^{12-}$-rings; no water is present in the formula; but both water and alkalies can be stuffed into the hole in the center of the rings. Halite is said to form through direct normal crystallization of magmas (p. 186). Wahlstrom seems to have been in a great hurry: there are unnecessary repetitions; a poor index that does not give reference to all places where minerals are listed; misspellings like trach*i*te, luxul*l*ianite, etc.

It is depressing to find a detailed description, ten pages long, of the calculation of the norm without any mentioning of Niggli's important introduction of the so-called "molecular norm" (1936). The weight norm of the CIPW-system is obsolete, and in my opinion it should never be used in its original form. Maybe most American petrologists do not know this, but a man writing a textbook has a duty to know.

T. F. W. B.

Rocks and Rock Minerals. By LOUIS V. PIRSSON and ADOLPH KNOPF. 3d ed. New York: John Wiley & Sons, 1947. Pp. vii+349; figs. 72; tables 50; pls. 36. $4.00.

The original first edition by Pirsson has excellent features from which students and teacher can fully profit. Obsolete statements and those not in harmony with modern concepts can be pointed out for the students and thus become of pedagogical value. The 1947 edition, however, must be measured by modern standards. It falls far short.

Poor judgment is used in the sequence in which the minerals are presented: mica, pyroxene, hornblende(!) . . . quartz . . . ! The sequence should be either genetic or chemical. Here no principle is followed. The whole is a confused mixture. Pyrite and apatite are placed under "Oxides." Chlorite and zeolite are placed under "Hydrous Silicates," but mica is placed with feldspar, etc., under "Silicates."

Under feldspar, perthite is *not* mentioned, although it is probably the most common feldspar mixture in rocks.

The presentation of the chemical composition of minerals is a hopeless mixture of right and wrong, old and new. The discussion of polysilicic acid, etc., is obsolete.

Amphiboles should not, "like pyroxenes, be considered to be metasilicate," and their compositions are *not* "too complex to be represented by simple formulas." Why does epidote contain a (OH)-group and a (SiO_4)-group, while mica has no (OH)-group, and idocrase has a (OH)-group but no (SiO_4)-group?

The formula for staurolite is radically wrong. To the Freshman it might be presented as a sillimanite structure interpenetrated by sheets of iron hydroxides:

$$\left\{\begin{matrix} Al_2SiO_5 \\ Fe(OH)_2 \\ Al_2SiO_5 \end{matrix}\right.$$

In the discussion of the chemistry of tourmaline, the terms *W* and *X* are suddenly used. If all the incoherent discussions of the mineral chemistry had been based on such conceptions from the very beginning, the book would have been much easier for the student to digest. Now great confusion prevails: there is no correspondence between related minerals; the formula for serpentine is presented differently from that of clinochlore, while the general formula of chlorite is altogether neglected; there is no formal connection between the various zeolites; and such monsters as $Na_4(AlCl)Al_2(SiO_4)_3$ for sodalite make it impossible for the student to get any understanding of mineral chemistry.

In the petrographic section, grains of magnetite enclosed in biotite are discussed: "They are evidently older than the biotite, because they are enclosed by it." This is far from true. By implication, albite lamellae should be older than microcline because they are enclosed by it! A flat slatement like: "Igneous rocks show in general this order of crystallization: first, the oxides of iron, then ferromagnesian minerals, then plagioclase feldspars, then alkali feldspars (and feldspathoids), and lastly quartz" is both untrue and harmful because it violates the fundamental laws of the physicochemistry of silicate melts. Both through the text and through graphical illustrations it is implied that the ferromagnesian minerals all cease to crystallize before the final stages of the crystallization history is reached. Yet no phase can cease to crystallize in a cooling system unless it is replaced by its reaction product. But plagioclase and quartz are clearly not reaction products of ferromagnesian minerals.

Knopf uses the old illustrations which, by now, are worn and poor; there is an almost complete lack of new references; coal has been forgotten in the classification of sedimentary rock. But these are trifles; one might call them misprints, and no book is free from misprints.

T. F. W. B.

An Introduction to Paleobotany. By CHESTER A. ARNOLD. New York: McGraw-Hill Book Co., 1947. Pp. ix+415; figs. 187. $5.50.

This new paleobotany text presents a systematic study of fossil plants at a level suitable to elementary and intermediate college classes in botany, paleobotany, and general paleontology. It fills a real need, inasmuch as it is the only text to be published in a number of years covering both the nonvascular and the vascular plants. The organization is excellent, and the space devoted to the various groups of plants is well distributed. The principal criticism of the book concerns the style, which is labored, in places trite, and burdened with cumbersome phraseology. This must reduce the effectiveness of the book as a text.

The approach to the subject is basically botanical, but part of the Introduction and one of the final chapters consider the geological aspects of paleobotany. In keeping with the purpose of the book, which is to present an up-to-date text on fossil plants, the classification is taken, with slight modifications, from J. A. Eames. Ten of the sixteen chapters comprise a systematic treatment of fossil plants within the framework of this classification. The second chapter is devoted to an extended, if somewhat elementary, account of the fossilization of plant materials. The third chapter deals with the nonvascular plants in summary style. The last two chapters give brief accounts of plants and environments and the systematics of paleobotany. Each chapter includes a well-selected list of references. Scientific terminology is introduced and freely used throughout the text. Although explanations of terms are included in the text, a glossary would prove of great use to the nonbotanical student.

Each chapter which deals with a major group of plants includes one or more sections which analyze the evolution of the group and its relationships to other related stocks. These analyses may be subject to criticism by botanists and paleobotanists, since they are necessarily somewhat subjective and since it is impossible in a text of this length to consider all evidence and all hypotheses. Nevertheless, the treatment of phylogeny is good and, for the most part, adequate for a text at this level. Only occasionally does dogma, so apparent in many texts, mask the true scope of thought on phylogeny.

Many of the illustrations are new, and few have appeared in other texts. Photographs are well selected and well described, but their clarity is reduced by the use of a rather coarse screen. Drawings are largely diagrammatic and executed with a simple line-and-stipple technique. Some are excellent, and others are rather crude, but all are easily understood.

This text is certain to be of great use to teachers in paleobotany and related fields. It has much to recommend it and relatively few serious defects. It may aid materially in reviving interest in the field of paleobotany, which in recent years has tended to decline in all but a few centers of active research.

E. C. O.

Outlines of Paleontology. By H. H. SWINNERTON. 3d ed. London: Edward Arnold & Co., 1947. Pp. x+393; figs. 367. $8.00.

In the Preface to the third edition of *Outlines of Paleontology* it is stated that the book has been thoroughly revised. This is something of an overstatement, since much of the text has been changed little or not at all and the illustrations with very few exceptions are the same. It is evident, however, that all sections have been carefully studied, for minor changes in phrasing and terminology occur throughout; and it may be supposed that the volume includes the full scope of changes which the author felt necessary.

Principal modifications have been designed to modernize the book by changing terminology, including new facts and trends of thought, and by changing or eliminating concepts which are no longer considered valid. The greatest changes are found in the sections concerning the Protozoa, Cephalopoda, Trilobita, and fishes. In each instance there has been considerable improvement. A tendency to place greater emphasis on ontogenetic and evolutionary development is evident in each of the revised sections. There has been less recasting of other sections, but those dealing with sponges, alcyonarian corals, and amphibians have been modified by additions or changes.

The changes have been distinctly conservative, which, in general, seems advisable in a standard textbook. The revision does not, however, fully reflect the amount of work and the changes in viewpoint which have taken place since 1930. Some sections, such as that on the Vermes, which were inadequate in the first and second editions, have not been modified materially. The third edition is distinctly superior to the second; but it would have been possible to improve it even more, had the author seen fit

to make more drastic changes in a number of sections.

E. C. O.

Principles of Micropaleontology. By MARTIN F. GLAESSNER. U.S. ed. New York: John Wiley & Sons, 1947. Pp. xvi+296, figs. 64, tables 7, pls. 14. $6.00.

The American edition of this work which was originally published in Australia in 1945, has now appeared and should prove extremely useful to micropaleontologists and particularly to students. As the name suggests, it reviews the entire specialized field of micropaleontology and includes much practical information not readily available elsewhere. The subject matter is presented in three parts and an Appendix.

Part I begins with a brief introductory chapter on the origin and present status of micropaleontology and continues with a classification and brief review of microfossils other than Foraminifera. This is the only special consideration given to the other fossils, and some parts are much too brief. For example, less than five pages are devoted to ostracodes and less than three pages (exclusive of text figures) to conodonts and scolecodonts combined. This part is concluded by a chapter on collecting, preparing, and studying microfossils, which is excellent.

Part II, devoted to the Foraminifera, constitutes about half the book. It begins with accounts of the life-history and general morphology of these organisms which are well organized, up to date, and, at the same time, brief but complete. The next chapter (over 100 pp.) is concerned with classification. The principles of classification are clearly explained, and previous classifications are compared. Then follows a systematic account of nearly 300 genera and subgenera arranged in 37 families. This section is very similar to the presentation of like material in Cushman's and in Galloway's well-known works but is less complete. Glaessner's classification in general follows Cushman's but is somewhat simplified and considerably altered in parts. A noteworthy feature is the grouping of families in 7 superfamilies, whose presumed phylogenies are discussed. Generic descriptions are brief but clear and adequate. The type species and stratigraphic range of each is given. Of particular importance are the excellent illustrated explanations of structural complexities which characterize certain groups. Unfortunately, this section as a whole is inadequately illustrated, and there are no cross-references between eight plates of Foraminifera and the text. A compensating feature, however, is a series of extremely useful tables which contrast the main morphological characters of more than 100 of the more important genera arranged by families. This part is concluded by a chapter on the paleoecology of both benthonic and pelagic Foraminifera.

The third part begins with a summary of the known stratigraphic occurrences of all types of microfossils and is continued by a chapter on the principles and application of stratigraphic correlation with special reference to microfossils and by another on the application of micropaleontology to petroleum exploration in various parts of the Eastern Hemisphere. The latter appears to be out of place in this book and is so general that it has little importance except for the presentation of some little-known historical facts and a very broad and incomplete tracing of certain contemporaneous ecological zones. Finally, a short chapter is devoted to a list of equipment needed by micropaleontologists and the suggested layout of a laboratory. This is much more closely related to the last chapter of Part I than to the foregoing portions of Part III.

The Appendix consists of a tabular synopsis of Glaessner's classification of the Foraminifera, with the stratigraphic range of each genus and the so-called "larger" Foraminifera distinguished; a table showing the equivalency of his families to Cushman's; and a bibliography of 30 pages arranged by subjects according to chapters in the text. Separate indexes are provided for subjects discussed, fossils mentioned or described, and authors to whom reference is made. The volume is concluded with a table showing the standard European stratigraphic scale.

This book is obviously the work of a practical micropaleontologist of wide experience. Some of the more general sections, like those on ecology and the principles of classification and stratigraphic correlation, reflect a sensible modern viewpoint and an understanding of the essential biological background of paleontology. Their application is not bounded by the limits of micropaleontology.

This book is less a handbook or reference work than is either Cushman's or Galloway's volume. With some supplementing of the nonforaminiferal microfossils, it will serve admirably as a very practical textbook of micropaleontology.

J. MARVIN WELLER

When the Earth Quakes. By JAMES B. MACELWANE, S.J. Milwaukee: Bruce Pub. Co., 1947. Pp. 288; figs. 251. $5.00.

There are various ways of appraising a book, one of which is for the reviewer to place himself, figuratively, in the position of the reader to whom the book is addressed and then determine to what extent the writer has succeeded in telling him what he wishes to know. The present book is one volume of a "Science and Culture Series" edited by Joseph Husslein, S.J., Ph.D., and is intended principally for the instruction of the lay reader on the subject of earthquakes and related phenomena. Putting himself in the position of the lay reader, the reviewer is obliged to disregard any previous knowledge he may possess about earthquakes and earth science in general, other than newspaper, magazine, and newsreel accounts and other such general types of information. Thus divested, he wishes to know what the directly observable facts concerning earthquakes are and, finally, what indirect conclusions may be deduced from these facts and *how the deductions are made*. If he is critical, he will refuse to accept assertions in the form of unsupported inferences.

Reading the book from this point of view, one is pleased to find the first three chapters, including eighty-five figures of photographs and maps, devoted to the description of what actually has been observed in earthquakes, with a brief outline of the principal facts pertaining to some two dozen separate earthquakes. In chapter iii, on "Kinds of Earthquakes," however, the argument becomes a little more difficult to follow when earthquakes are divided by causes into the classes of "tectonic," "volcanic," and "plutonic" earthquakes. The first two classes are substantiated fairly conclusively by the evidence presented, but the last, the "plutonic" type, is supported only by the authority of the author's assertion.

The next four chapters (iv, v, vi, and vii), entitled "Why Earthquakes?", "When and Where?", "Field Study of Earthquakes," and "Sea Quakes and Seismic Sea Waves," are moderately straightforward. The first two deal mostly with direct geological evidence, and the third discusses principally the Abridged Wood-Neumann Scale of seismic intensities and its use in seismic mapping by means of isoseismal lines.

There is, however, in the third of these chapters a logical inversion in a section devoted to the nature of earthquake motion, wherein *P*-waves and *S*-waves are discussed and are asserted to be, respectively, dilatational and transverse elastic waves, notwithstanding the fact that *P*- and *S*-waves are unknown to the reader until he is introduced to seismograms in a later chapter. Also no evidence is presented in support of the assertions as to the nature of the waves.

The remainder of the book, chapters ix–xvii inclusive, is devoted to various aspects of instrumental seismology, including earthquake, engineering, and prospective seismology, with a final chapter on microseisms and their relation to storms at sea. The treatise on earthquake seismographs is very good; but, when the reader expects to learn how seismograms are employed to decipher the nature of the interior of the earth or to determine the focal depth of plutonic earthquakes, he is disappointed. Seismograms showing *P*- and *S*-waves are reproduced, and it is asserted, but with no supporting evidence, that these travel *through* the earth (whereas another type of wave is propagated along the surface).

The chapters on engineering applications of seismology and a brief account of prospecting methods are appropriately done for present purposes; also that on microseisms. An excellent sheet of ten seismic prospecting records is presented in Figure 220, showing the correlation of about five different reflection horizons.

Appendixes containing a brief outline of geology, an excellent seismic bibliography of 105 titles, and a glossary of terms are added, which greatly increase the usefulness of the book.

From the foregoing account it will be inferred that, on the whole, this book achieves its objective rather well. There are, however, as indicated, several serious lapses of logical consistency, and it is regretted that a better job was not done in presenting at least the simplest deductions from seismic records.

It is also regrettable that a shadow should have been cast upon the scientific integrity of the book by its editor, who in his Preface, after reciting a case in which an ignorant Italian workman attributes earthquakes to a "scourge of God," proceeds to assure the reader: ". . . he [the workman] was correct in supposing that these natural phenomena occur by the disposition of God's Providence."

M. KING HUBBERT

Some Structural Features of the Intrusions in the Iron Springs District. By J. H. MACKIN. ("Guidebooks of the Geology of Utah," No.

2.) Salt Lake City: Utah Geological Society, 1947. Pp. 62; figs. 12.

During the war years the steel industry of Utah, Colorado, and California depended largely on the iron-ore deposits of Iron Springs, Utah, located about 220 miles south-southwest of Salt Lake City. This paper presents a stimulating preliminary interpretation of the origin of the deposits, which were investigated by Mackin and his assistants under the auspices of the United States Geological Survey, aided by drilling and trenching operations by the United States Bureau of Mines.

Three small intrusions of quartz-monzonite porphyry are lined up in a northeast-southwesterly direction and have domed and faulted contacts with a series of Jurassic (Homestake, "Entrada") and Upper Cretaceous to Eocene (Iron Springs, Claron formations) sediments. At the base of this series is found, in near-by areas of the Colorado Plateau, a gypsum horizon with interbedded limestone and shale, which, in turn, rests on the thick Navajo sandstone. Following a local pre–Iron Springs disturbance that brecciated the Homestake limestone in places and brought about local erosion of the Entrada series, the monzonite magma is believed to have broken through the resistant Navajo sandstone along a zone some distance east of the present exposures, to have spread along the easily yielding gypsum horizon, and to have lifted the overlying strata to form laccolith- or bysmalith-like bodies of monzonite porphyry.

According to Mackin, the origin of the iron ores in the contact zones of the intrusions is closely related to fracturing of the newly consolidated igneous rocks. Thus the western border of the Three Peaks intrusion is penetrated by subvertical joints that strike approximately at right angles to the nearest contact. The fractures are believed to have been caused by distension of the monzonite porphyry at a stage when the magma had already formed a chilled border and cooling was advancing inward. Other fractures dip into the intrusive, striking approximately parallel to the contact. The first fracture system indicates elongation of the consolidating mass in subhorizontal directions, more or less parallel to the strike of the border; the second system records a marginal lengthening of the cooling mass in directions down-dip along the domed roof. Other fractures seem to occupy intermediate positions between these two systems and may curve from the one into the other principal direction.

These conspicuous fractures are commonly coated with magnetite selvages, a fraction of an inch to several feet thick. The author assumes that the expulsion of iron oxide was essentially a deuteric process, comparable to the release of volatiles from cooling basalt along contraction joints, drawing its material from the cooling rock near the joints. Numerous analyses showing deficiency in iron in monzonite porphyry directly adjacent to magnetite selvages are cited in partial support of this theory. Particularly strong doming or expansion in local areas is thought to have facilitated the opening and wide gaping of suitable fractures, whereas shearing between the chilled border and the fractured zone of monzonite next below has inhibited the outward expulsion of emanations. Marginal fault zones, cutting across the intrusion and the wall rocks in places, are believed to have permitted the iron-precipitating emanations to reach the Homestake limestone, in which case replacement ore bodies of prodigious size were formed.

As the author emphasizes, several points in this theory of the origin of the ore deposits have not yet been determined quantitatively. Even so, the structural study of the district illuminates significantly the mechanism that permits transfer of iron-precipitating emanations from the interior of an intrusion through an intensely fractured outer zone, leading under favorable conditions to large-scale replacement ore bodies in carbonate rocks. Structural factors that facilitate such transfer and others that impede or prevent it are clearly identified; the usefulness of detailed areal structure surveys for better understanding of problems of ore concentration is convincingly shown; and guiding principles for locating additional favorable areas of ore concentration are pointed out. The forthcoming full report on the area, now being prepared by the Geological Survey, should prove interesting reading.

R. BALK

The Pegmatites of Central Nigeria. By R. JACOBSON and J. S. WEBB. (*Geol. Survey of Nigeria Bull. 17* [1946].) Pp. 61 (small 4to); pls. 6; figs. 10; folded maps 4. 10/6 from The Technical Bookshop, 724 Salisbury House, London Wall, London.

Although this report is a product of "war research," some two years were devoted to its

preparation. Several hundred pegmatites (a few of which are briefly described in an appendix), and some four hundred thin sections were examined. Sixteen photomicrographs, showing some interesting details, and a generalized paragenetic diagram are included in the report. As in most studies of pegmatites, many of the conclusions reached are not sufficiently buttressed by a logical chain of evidence; nevertheless, this report is a publication of much more than average value.

The Nigerian granites are divided into "Older" and "Younger." The former embraces a variety of pre-Cambrian granites which probably belong to several different periods of plutonic activity; these are genetically related to the pegmatites. The younger granite occurs in north-central Nigeria; it contains biotite and riebeckite and has given rise to the major (alluvial) tin deposits.

The pegmatites occur as fairly tabular dikes up to a mile or more in length and 30 feet or more in width; the more highly albitized ones have gentle dips and show pinch and swell structure. Simple pegmatites occur in the granites; albitized pegmatites carrying cassiterite, columbite, etc., are found in the surrounding metamorphic rocks and are not conformable with the foliation of the host rock; quartz-tourmaline veins, locally (fig. 4) closely related to the pegmatites, may be conformable with the foliation of the country rock.

The first stage in the development of the pegmatites is generally characterized by perthitic microcline and quartz, and a slightly earlier quartz-muscovite ($K_2O:Na_2O = 8:1$) border zone. Minerals of this stage were followed by the deposition of albite, some of which was injected among the earlier pegmatite minerals to form a fine-grained, sugary, pseudo-aplitic rock. Part of the albite is coarse cleavelandite, with which is associated columbite, cassiterite, muscovite ($K_2O:Na_2O = 4:1$), phosphates, etc. The deposition of the albite and associated minerals was succeeded by formation of the quartz-tourmaline veins; minor kaolinization and chloritization were the last processes operative.

The early formation of small poikilitic crystals of cleavelandite, as advocated by Andersen and the reviewer, is not recognized by Jacobson and Webb. Such early-formed cleavelandite, however, seems to be shown in plate II, figures 3 and 4. The authors have presented convincing evidence that the albitization process is characterized in part by replacement of the microcline. The nature of the wall rock has little or no effect on the mineralogy of the pegmatites.

D. J. F.

Le Congo physique. By MAURICE ROBERT. 3d ed. Liége: H. Vaillant-Carmanne, S.A., 1946. Pp. 449; figs. 70; pls. 29.

The first edition of this authoritative work was prepared under the auspices of the Comité Spécial du Katanga in 1919 and the second in 1941. While no great time has elapsed since the appearance of the second edition, there have been some notable new contributions to our knowledge of central Africa, which have been utilized by the author to bring the present volume up to date.

In this treatment the Congo geology has been, to a helpful extent, tied in with that of South Africa, enabling the reader to get a broad general picture, as well as the regional details. The mineral deposits are of great importance, and some of them of world-wide interest. Full treatment is also given to the evolution of the surface relief, together with the hydrographic system, and to the climate. A long chapter is devoted to biogeography.

R. T. C.

A Yanqui in Patagonia. By BAILEY WILLIS. Stanford University: Stanford University Press, 1947. Pp. 152; figs. 32. $3.00.

The Yanqui is Bailey Willis. The ever youthful nonagenarian has been persuaded by appreciative friends to write a book of reminiscences of his unusually eventful life. Perhaps these friends urged an autobiography, but the resulting literary production is that only in part; the narrator is too much of an artist to act like an ordinary biographer. Instead, he has painted only certain parts of the whole picture, giving them a vividness and charm peculiarly his own.

Part I, "Before Patagonia," introduces the Yanqui. His graduation from the Columbia School of Mines coincided with the establishment of the United States Geological Survey, and his professor of geology recommended him to Clarence King. King turned him over to Pumpelly, who sent him on a solitary ride of 600 miles through the valleys and mountains of the south to find the "ore banks" from which the Confederates made iron. Next he was directed to run down reports of iron ores north of Lake Superior, which he did in a long trip with Ojibway Indians that began in birchbark

canoes and ended on snowshoes. Two years later, Pumpelly assigned him the task of surveying coal lands, believed to occur widely in the dense forests between Puget Sound and the Cascades, for the Northern Pacific Railway, then being built. Some of the most interesting pages of the book tell the story of this formidable undertaking.

Nearly thirty years ago, the reviewer was impressed by the following in Raphael Pumpelly's *Reminiscences* (vol. II, p. 627) (the scene was Tacoma):

> There was a trial of a ship's captain for extreme brutality. The captain swore it was the only way to manage his crew. The prosecuting attorney hurled at him: "Do you mean to say that you and your mate can't manage a half-dozen sailors when the boy Willis up in the woods, easily and alone, controls ten times as many of the toughest scoundrels in the country?"

Pumpelly's reference is readily understood, on reading the present book, as just a typical reflection of Willis' surpassing skill in dealing with men, whether though miners, lumberjacks, hostile Indians, or smooth Argentine bureaucrats. The stories of these dealings make delightful reading.

A single short chapter, "The United States Geological Survey," is all there is to represent a major hiatus between the author's early exploits and the Argentine project of 1910–1914. But it does give some revealing sidelights, particularly on Powell and Gilbert.

Part II, "Patagonia," is the greater part of the book. Don Ezequiel Ramos-Mexia, minister of public works of Argentina, was facing grave difficulties in prosecuting his plans for the development of lands still belonging to the nation. Water was the great need and, since semiarid areas in the United States had been made productive by drilling artesian wells and building railroads, Ramos-Mexia had built many miles of railroads and caused many wells to be sunk, but he had not found water. An American geologist to head a "Comision de Estudios Hidrologicos" was his remaining hope, and he contracted Bailey Willis.

Willis went at the job with an enthusiastic party of young Americans, but their geological survey proved artesian water to be a vain hope; a dam-and-reservoir project was the best they could offer. The Minister then put them to surveying the best route for a southern transcontinental railway across the Andes. Their extensive explorations Willis enlivens with tales of the Conquistadores, the city of Los Cesares, the cave man of Lost Hope Fiord, and other delightful bits of local color. Beautiful Lago Nahuel Huapi was the focus of many of the Yanqui's activities, and in planning a future development of this area with railroads, an industrial city at the east end of the lake, and a national park beyond, he made some notable contributions, indifferently appreciated by Argentine officialdom.

R. T. C.

On Seismogram Types and Focal Depth of Earthquakes in the North Japan and Manchuria Region. By EIJO VESANEN. ("Isostatic Institute of the International Association of Geodesy Publications," No. 15.) Helsinki, 1946. Pp. 25; figs. 14.

On the Gravity Field and the Isostatic Structure of the Earth's Crust in the East Alps. By PAAVO E. HOLOPAINEN. ("Isostatic Institute of the International Association of Geodesy Publications," No. 16.) Helsinki, 1947. Pp. 94; diagrams 5; maps 2. $1.50.

PUBLICATION NO. 15

The first is a sequel to an earlier paper of 244 pages published by Vesanen in 1942, on the type-evaluation of seismograms. The reviewer has not seen the earlier paper, but it evidently presented the thesis that there was a recognizable character difference in seismograms from shallow and deep foci and, furthermore, that the depth of transition was not constant from area to area.

The present paper is an application of that thesis to the earthquakes of northern Japan and Manchuria, recorded at Helsinki between January 1, 1925, and June 30, 1940. A complete table is given for these quakes, showing, besides their computed focal depths, their seismogram types, NJa 1, NJa 2, and NJa 3, based upon the character of the *P*- and *S*-waves. These three character types correspond, in the author's judgment, to three different physical layers in the order of increasing depth, in which the different types of earthquakes originate.

On a map showing the location of the epicenters, the shallow-focus quakes (NJa 1 type) are clustered mostly in a linear belt along the continental slope between Honsyu and the foredeep to the east. The shocks of intermediate depths occur somewhat westward of this zone, and the deep shocks still farther to the west.

Although photographs of the *P*- and *S*-records of a number of earthquakes are shown, it is not clear to the reviewer from the present paper what the diagnostic features of the different types are. It also appears that a strong element of personal judgment is involved in the classification. This may account for one of the principal conclusions of the paper. In certain quakes the author has found that *P* has a shallow character, whereas the character of *S* is intermediate. From this he concludes that the *P*- and *S*-waves have originated *in different layers*.

To the several seismologists and physicists with whom this hypothesis has been discussed it appears absurd and physically impossible. One questions, therefore, whether a better explanation may not be found in the unreliability of the criteria and the fallibility of subjective judgment.

PUBLICATION NO. 16

The second of these papers is an analysis of the gravity data of the region of the eastern Alps. This area comprises roughly the quadrangle bounded by the 45th and 49th parallels of latitude and the 9th and 17th east meridians.

The gravity data for the area consist of 301 stations, all but 91 of which were measured prior to 1894. The most recent stations were the 91 measured between 1910 and 1932. Intercomparison between different surveys permitted the elimination of all obviously "wild" values, some of which were apparently in error by as much as 50–60 milligals. For the remaining stations, free-air, Bouguer, and local Airy-Heiskanen anomalies were computed, the latter for each of the seacoast crustal thicknesses of $T = 20$, 30, 40, and 60 km. In certain selected areas, tests of regional versus local compensation were also made by computing regional anomalies for various radii of assumed regional compensation, using the method of Vening Meinesz.

Maps of iso-anomaly lines are shown for the Bouguer anomalies and also for the Airy-Heiskanen anomalies for $T = 20$ km. These show definite axial trends parallel to the tectonic axis of the mountain range. Across this axis several profiles are plotted, showing, in addition to the topography, the profiles of free-air, Bouguer, and the two or three Airy-Heiskanen anomalies of least amplitude.

The Bouguer anomalies, as usual, are the largest, showing a broad negative trough of a depth of -175 milligals along the axis of the range. Next comes the free-air anomaly, also dominantly a negative trough, and, finally, the various isostatic anomalies, the smaller of which show an amplitude of variation of from about -25 to $+100$ milligals, with alternate ridges and troughs parallel to the axis of the range.

In addition to the graphical representation of the data, they also were treated statistically. The customary sums of the squares of the various types of anomalies were computed and tabulated. Also a new test was introduced, which the author thinks—and the reviewer agrees—is more diagnostic. This was a statistical correlation of each class of anomaly with the difference between the elevation of the station and that of the surrounding region. The best anomaly by this criterion would be the one having the smallest elevation correlation.

For the region as a whole the best results were given by the Airy-Heiskanen anomaly for $T = 20$ km. and local compensation. In certain parts of the region better results were given by $T = 30$ km. and in others by regional compensation to a few tens of kilometers. Even so, there remained belts of positive and negative anomalies of 40–50 milligals. These the author explains by the buckling hypothesis of Vening Meinesz. One negative anomaly of 40–50 milligals in the northern part of the area was thought to be produced by light-sediments some 3–10 km. thick.

While this is a very able study, it seems to the reviewer that there are two conflicting interests which might be better served by separate methods of analysis. The first of these is a test of the isostatic hypothesis; the second is an inquiry into the actual distribution of anomalous masses. The methods used here and in other studies of this kind are explicitly designed to test the hypothesis of isostasy; what the reviewer would like to see would be comparable methods uncontaminated by any kind of the apriori hypothesis and designed expressly for the purpose of yielding the maximum information as to the magnitude and disposition of anomalous masses.

He also would like to see pendulum data supplemented and supplanted by gravity-meter data accurate to 0.1 milligal.

M. KING HUBBERT

Two Problems of Marine Geology: Atolls and Canyons. By PH. H. KUENEN. (*K. Akad. Wetensch. Amsterdam Verh., Afd. Naturk.*, Tweede Sectie, Vol. 43, No. 3.) Amsterdam, 1947. Pp. 67.

This publication, based on two lectures delivered at London University in November, 1946, is a well-considered appraisal of two outstanding geological problems.

In the section on atolls, the results of recent borings on the island of Maratoca, northeast of Borneo, are described for the first time. The deepest boring penetrated coral limestone, coral detritus, and marly limestone to a depth of 429 meters and is believed to be evidence of subsidence of at least 500 meters during coral upgrowth. Following a review of the principal theories of origin, a theory of *glacially controlled subsidence* is presented. According to this theory, preglacial atolls and barrier reefs were formed by subsidence; during glacial stages platforms were eroded at glacial sea level; and, with postglacial rise in sea level, the corals grew upward along the margins of the platforms. It is emphasized that important erosion was accompanied by chemical attack, which may have permitted continuous coral growth during the glacial stages.

The section on submarine canyons presents a review and analysis of critical data and principal hypotheses of origin. Turbidity currents, due mainly to wave turbulence and partly to slumping, are favored as the most reasonable explanation offered so far. Tank experiments by the author and certain features of the canyons themselves are presented in support of this view. It is recognized that the major objection to the hypothesis is the hardness of certain rocks which had to be eroded, notably in the California canyons.

L. H.

Field Conference in the Bighorn Basin: Guidebook. Arranged by the UNIVERSITY OF WYOMING, WYOMING GEOLOGICAL ASSOCIATION, and the YELLOWSTONE-BIGHORN RESEARCH ASSOCIATION. 1947. Pp. 277; figs. 51; pls. 18; maps and sections in pocket. $4.00. Obtainable from the Wyoming Geol. Assoc., P.O. Box 545, Casper, Wyoming.

In August, 1946, the above-named institutions conducted a field conference in the Bighorn Basin of Wyoming to see and discuss the salient features of that exceptionally interesting region, where geologists have been very active in recent years. At this conference, Fellows of the Geological Society of America, participating as special guests, inaugurated a Rocky Mountain Section of the Society. The large guidebook, carefully prepared for the occasion, opens with generalized stratigraphic sections and then proceeds with the detailed road logs for the four days of the conference. For the last two days, seven optional trips were offered; and, finally, since the participants could not get out of the Bighorn Basin without crossing its very significant border structures, they were given "exit road logs" for five alternative routes, together with two short side trips. Accompanying the road logs are concise general statements, local columnar sections, cross sections, sketch maps, and fourteen plates of photographs grouped together for convenience.

Twenty special papers make up the last two-thirds of the volume, devoted primarily to stratigraphy, structural relations, and typical oil fields. It is really invidious to call attention to but two of these individual contributions; but readers who relish radical departures from current interpretations will find such in J. Hoover Mackin's strong contention that "the Middle Rockies are essentially in a first, not a second or third cycle of erosion" and in Walter H. Bucher's conviction that there never was a great "Heart Mountain overthrust" sheet. Mackin concludes that the middle and late Tertiary relief of the Beartooth and Bighorn ranges was essentially a continuation of the relief developed by Laramide movements, decreased, on the one hand, by erosion and, on the other, by aggradation of lowlands, and that the subsummit surface is not an early Tertiary peneplain but is instead a pediment, probably formed much later at not more than 2,000 ± 1,000 feet below the present altitudes of its remnants. Bucher regards the widely scattered, but relatively small, allochthonous limestone masses of the "Heart Mountain overthrust" not as remnants of a continuous orogenic thrust sheet but as individual blocks that have slid down slopes basinward under the action of gravity. Both men have presented much evidence supporting their interpretations.

Conferences of this sort are becoming popular for their effective dissemination of knowledge and their stimulus to further research. Participants gain the most; but the guidebooks, filled with judicously assembled information, can spread the benefits much more widely. They are very handy as books of reference.

R. T. C.

COMMUNICATIONS AND ANNOUNCEMENTS

THE NATIONAL RESEARCH COUNCIL HAS APPOINTED A COMMITTEE ON GEOPHYSICS, ADVISORY TO THE OFFICE OF NAVAL RESEARCH

Acting upon a request from Admiral Paul F. Lee, chief of Naval Research, the National Research Council has appointed a committee of active scientific investigators to advise the Geophysics Branch of the Office of Naval Research regarding scientific and related aspects of their research programs. The committee is as follows: Walter H. Newhouse, *chairman;* Harry H. Hess, *vice-chairman;* and Roland F. Beers, Maurice Ewing, Ellis A. Johnson, Lester E. Klimm, William C. Krumbein, William W. Rubey, and J. Frank Schairer.

Dr. R. C. Gibbs, chairman of the Division of Mathematical and Physical Sciences of the National Research Council, acts as administrative adviser to the committee, in collaboration with Dr. Arthur Bevan, chairman of the Division of Geology and Geography.

The committee held its first meeting on January 7 and 8, 1948, in Washington, D.C. As stated by Dr. Roger Revelle, head of the Geophysics Branch of the Office of Naval Research, that branch is charged with the responsibility within the Navy Department of sponsoring basic research in appropriate fields of earth sciences through financial and other support of worthy projects. Functioning within this general framework of responsibility, the committee will, for the present, restrict its consideration to research problems dealing with the crust of the earth and the properties of the earth as a whole.

Since it is part of the policy of the Office of Naval Research to sponsor research in fields not adequately covered by other agencies, the Geophysics Branch, with the committee's concurrence, has established the following objectives for research within the fields covered by the committee:

1. To foster, in co-operation with other agencies, geological, geographical, and geophysical explorations of little-known areas of the earth, such as the islands of the western Pacific and the Arctic and Antarctic. Such exploration may include all aspects of the natural environment and problems of human and economic geography and ethnography, as well as the more limited objectives implied in the terms "geology" and "geophysics."

2. To conduct laboratory and field studies leading to a greater understanding of the properties and processes existing in the outer hundred kilometers of the earth's crust.

3. To develop instruments and techniques for determination of the earth's properties, for example, universal airborne magnetometer equipment.

The Office of Naval Research has adopted the policy of avoiding formulation, detailed direction, and the "farming-out" of projects for basic research, in the belief that maximum progress and results will be realized if projects for investigation grow out of the ideas and interests of the investigators themselves. The committee warmly indorses this policy and will seek at all times, through advice and recommendations, to further its operation to the maximum degree possible. The submission of significant and well-organized research proposals will be helpful in this connection.

For further details consult the Office of Naval Research, Navy Department, Washington 25, D.C., or the National Research Council, 2101 Constitution Avenue, Washington 25, D.C.

UNIVERSITY OF KANSAS PALEONTOLOGICAL CONTRIBUTIONS

The first numbers of a new scientific publication, entitled the *University of Kansas Paleontological Contributions*, have been issued (page size, 8 × 10¾ inches; full-tone plates). Separate series bearing the names of phyla are established for articles dealing with representatives of these phyla; and ultimately title-pages covering a group of related articles will be issued, for use in binding.

Copies of the *Contributions* will be distributed to individual paleontologists on request without charge other than a fee of 25 cents for mailing.

DRAINAGE ALIGNMENT ON THE SAGANAGA GRANITE

The drainage pattern on igneous rock masses usually shows no evidence of structural control. In a recent paper (1947, p. 356), the writer states that the numerous lakes on the homogeneous Saganaga granite in northeastern Minnesota have no definite alignment. Dr. F. F.

Grout, who has made a careful study of the Saganaga batholith (1936), states that there is a strong relationship of the drainage pattern to a systematic internal structure curved around a dome.[1] There is an "elliptical" arrangement of the lakes which is not closed on the east. The main control, according to Grout, must be the cross-joints and dikes (normal to the flow-lines) and inclusions and schlieren streaks having easily weathered minerals.

REFERENCES CITED

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KARL VER STEEG

INTERNATIONAL GEOLOGICAL CONGRESS, XVIII SESSION GREAT BRITAIN, 1948

General Secretary: GEOLOGICAL SURVEY AND MUSEUM
EXHIBITION ROAD, LONDON, S.W. 7

29th January, 1948

Dr. H. R. Aldrich,
The Geological Society of America,
419 West 117th Street,
New York 27, New York

DEAR DR. ALDRICH,

Thank you very much for your letter of January 7th. Professor Read certainly found his visit and the welcome you gave him most enjoyable and stimulating.

He tells me that he found that certain difficulties in obtaining shipping passages are being experienced by American geologists who wish to join the Congress; and I have received directly one or two complaints and enquiries about the same point. I have taken the matter up with Cooks and with Cunard White Star (who gave us assurances some time ago that traffic to the Congress could be adequately handled); and they are doing all they can from this end to make sure that members are accommodated and that their American offices are alive to the urgency of the situation. Cooks think that the trouble may be in part that it is not always possible at the moment to assure an applicant of a specific sailing date, even though there is no doubt that it will eventually be possible to provide a berth for him about the time he specifies. I understand that additional boats are very likely to be brought into service on the Atlantic route before the summer: but that negotiations on this are not yet quite complete.

Professor Read also found that some American colleagues were dubious about coming over here and making further inroads upon our food supplies. There may also be the very understandable point as to whether it is worth making the trip in view of reports of meagre fare here.

It seems likely that the food situation probably appears worse, in Press reports, than it actually is. We cannot in present circumstances entertain Congress members as lavishly as we should wish. Nevertheless, we have done our best to provide for the comfort and refreshment of members, and think that they may find conditions less rigorous than reports abroad may suggest.

I may mention that, in addition to Government, University and other receptions in London, a large number of civic authorities, industrial firms and other bodies are arranging special local hospitality for the excursion parties.

We greatly hope that despite any present discouraging factors, the number of members from U.S.A. and Canada will approach the number (some 500, including relatives) who provisionally registered in response to the Third Circular. It was largely because of this great response by prospective members from North America that we further extended last autumn our excursion programme; and the success of the Congress will largely depend upon their presence.

Please be assured that on our part we shall spare no effort to satisfy the needs of our guests.

Yours very sincerely,

A. J. BUTLER
General Secretary

[1] Personal communication, September, 1947.